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QUARTZ VEINS IN THE OUACHITA MOUNTAINS OF ARKANSAS AND OKLAHOMA (THEIR RELATIONS TO STRUCTURE, METAMORPHISM, AND METALLIFEROUS DEPOSITS).[1]

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ABSTRACT.

An important chapter of the total geologic history of the Ouachita Mountains is revealed by the quartz veins and crystals. These and the associated minerals are hydrothermal deposits of probable magmatic origin, formed during the closing stage of the mid-Pennsylvanian orogeny. The metalliferous deposits of the Ouachita Mountains appear to have been formed at the time of the quartz vein deposition. This fact should be considered in dating the lead and zinc mineralization in other areas of the Mississippi Valley region.

INTRODUCTION.

THE preparation of this address arises from the pursuit of my hobby—the collection of Arkansas quartz crystals—which dates back to my first visit to the quartz crystal mines in the Crystal Mountains of Arkansas in 1907, the first year that I was given a geologic field assignment. In that year I became a student of the structure, stratigraphy, mineral resources, and other geologic features of the Ouachita Mountains of western Arkansas and southeastern Oklahoma, and my studies have been continued during

[1] Address of retiring vice-president for the section on geology and geography of American Association for Advancement of Science at annual meeting of Association in Dallas, Texas, Dec. 29, 1941.

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many ensuing years, but other duties have permitted only occasional brief trips to the area during the past 15 years.

Quartz veins are numerous and widespread in the Ouachita Mountains, both in Arkansas and Oklahoma, and associated with them at numerous places in Arkansas are quartz crystal deposits. The formation of the veins and crystals is related to the Pennsylvanian structural deformation and metamorphism of the thick sequence of Paleozoic rocks that are exposed in the Ouachita Mountains. My purpose at this time is to describe the crystals and veins and discuss this relationship.

QUARTZ CRYSTALS.

The Arkansas traveler, who passes through the west-central part of the State, finds many dealers of quartz crystals occupying roadside stands along U. S. Highways 70 and 270 and other highways near Hot Springs, Crystal Springs, and Paron. The crystals on these stands have been mined at numerous places in the Crystal Mountains and other localities in a belt of country 25 miles wide and 75 miles long extending from Paron near Lake Winona westward almost to Mena, near the Arkansas-Oklahoma line. (Fig. 1.)

Before DeSoto's exploration of this area and its settlement by white people, the quartz crystals were shaped into arrowheads by the Indians, but since then the crystals have been utilized in the manufacture of optical equipment and jewelry, including beads and ring sets. Stones that are cut from crystals are sold in Hot Springs under the trade name of "Hot Springs diamonds." Most of the quartz crystals from Arkansas, however, find their way into the mineral collections of institutions and individuals, and a relatively large volume is utilized in the construction of water fountains and religious and memorial shrines. The value of the natural crystals sold in 1941 is estimated to be about $12,000.

Most of the crystals are milky white, but many are clear; others contain both clear and white quartz in different proportions. Some of the larger crystals, weighing half a pound or more each, are suitable for the manufacture of radio oscillators. I estimate

that the entire supply of clear quartz crystals, weighing half a pound or more each, would normally not exceed 1,000 pounds each year. This quantity is small in comparison with our normal annual domestic requirements of possibly 5 or 6 tons and in comparison with our much greater emergency requirements.

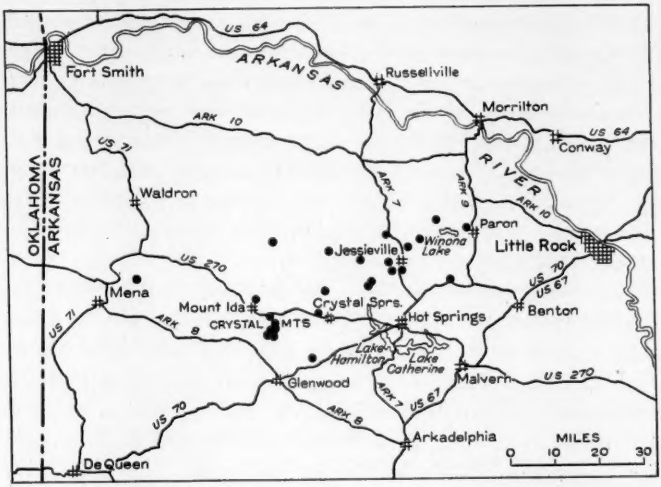

FIG. 1. Quartz crystal deposits (large dots) in western Arkansas.

The quartz crystals are briefly described here. They will, however, according to present plans, be more fully described in another paper to be prepared by me in collaboration with Messrs. W. T. Schaller and C. S. Ross.

The individual crystals generally possess the common symmetrical hexagonal shape consisting of the 6 prism and 6 pyramid faces but really there is a great variety of other faces and shapes including tabular crystals. The crystals at different localities differ in clarity, size, and shape. All of them, however, are euhedral crystals of the low-temperature type, presenting a rhombohedral symmetry, by unequal development of the pyramid faces.

In addition to the clear and white crystals there are several localities where beautiful crystals of smoky quartz are found. These occur in the same localities as the clear and white crystals but they lie in bodies that appear to be separated from them. Also, negative crystals, commonly in smoky quartz, that enclose white clay and water, are known at three localities.

Individual crystals vary greatly in size, ranging from a small fraction of an ounce to 330 pounds. Loose single crystals constitute a large proportion of the market quartz. Such crystals are usually broken at one end. Many crystals are, nevertheless, doubly terminated. The loose single crystals, whether doubly or singly terminated, have been broken by natural processes or by man from comb quartz which lines cavities in sandstone or in vein quartz. The parts of the cavities not occupied by the crystals are filled with red, yellow, and white clay.

The crystal clusters and also the detached single crystals are obtained from small openings, chiefly trenches and pits, as much as 30 feet in depth. The clusters present a great diversity of shape and size. Many of them are tabular, the crystals having grown outward from a relatively smooth surface; some are curved or irregular; and some reveal crystals projecting in all directions. The largest cluster obtained, free of wall rock, of which I have knowledge, weighs 750 pounds, and the largest cluster including the sandstone wall rock weighs 1½ tons.

QUARTZ VEINS.

Although the quartz crystals are abundant and are found at numerous places in Arkansas, vein quartz is even more abundant and more widely distributed. Most of the veins and crystals are restricted to a belt, 30 to 40 miles wide, extending in a west-southwesterly direction from Little Rock, Ark., to Broken Bow, northern McCurtain County, Okla., a distance of about 150 miles. How far the vein-bearing rocks extend eastward beyond Little Rock is not known, for there Upper Cretaceous and Tertiary strata of the Gulf Coastal Plain conceal them. But to the south-

west the rocks containing quartz veins extend beneath the Lower Cretaceous strata of the Coastal Plain and have been encountered in deep wells both in southeastern Oklahoma and northeastern Texas.

The belt of quartz-bearing rock coincides with the main anticlinorial belt of the Ouachita Mountains. In this belt is exposed a sequence, about 25,000 feet thick, of faulted and closely folded sedimentary rocks, chiefly shales and slates, some sandstones, and relatively minor thicknesses of limestone, chert, and novaculite, that range from Cambrian, through Ordovician, Silurian, and Devonian, to Pennsylvanian age. The pre-Pennsylvanian rocks are exposed almost continuously along the axis of the anticlinorium (Fig. 2).

The veins are widest and most numerous in the central part of the main quartz-vein belt, where they occur in the shales, slates, sandstones, and other rocks; but along and near the borders of the belt the veins are usually confined to beds of sandstone that lie between thick beds of shale.

The veins range in width from a small fraction of an inch to as much as 30 feet in Arkansas and to as much as 100 feet in Oklahoma. The quartz of the veins, like most of the quartz crystals, is milky white and vitreous; it is generally massive, and most of it is free of associated minerals. Over large areas the veins are so numerous that the residual fragments of quartz have accumulated in sufficient quantities to whiten the surface.

The veins were formed by the filling of open fissures and some of them were produced by the growth and consequent crowding together of comb quartz so as to fill or partly fill the fissures. Evidence of replacement of wall rock by vein material has been noted in only a few specimens that reveal partial replacement of sandstone wall rock by quartz crystals. The great width of many of the veins would seem to require successive waves of quartz deposition following reopening of fractures along the veins at different times.

Pure white quartz could readily be obtained in large quantities for commercial purposes from the largest veins, which occur in

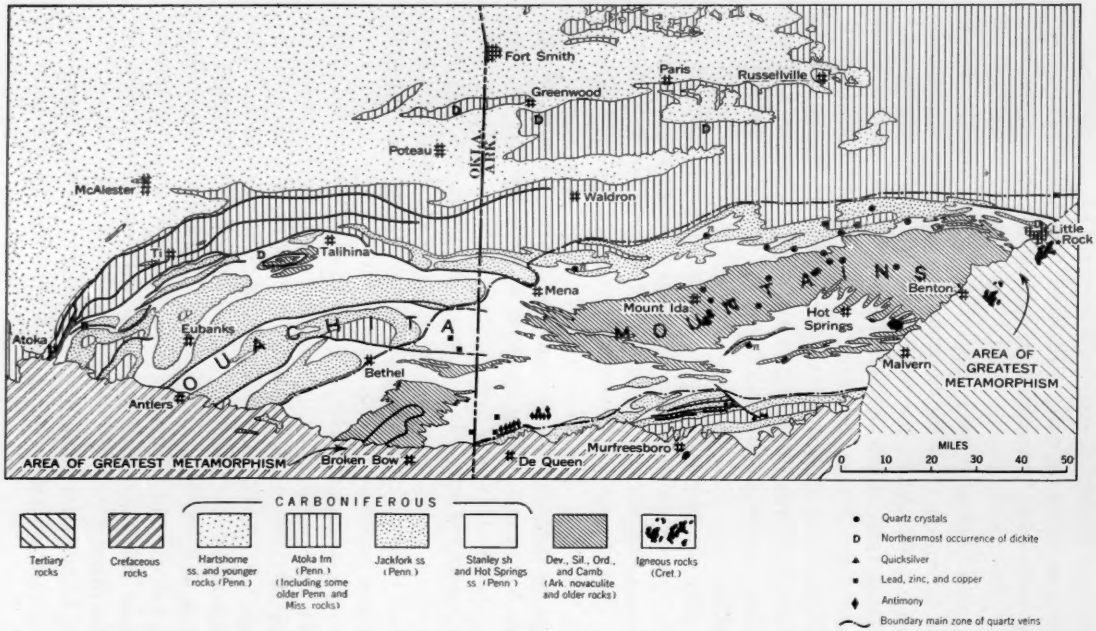

FIG. 2. Geologic map of Ouachita Mountains and parts of adjoining regions, Arkansas and Oklahoma, showing occurrence of quartz and other minerals.

n at quartz locality denotes negative crystals.

the region just west of Little Rock, Ark., and north of Broken Bow, in northern McCurtain County, Okla.

MINERALS ASSOCIATED WITH QUARTZ CRYSTALS AND VEINS.

Relatively few minerals are associated with the quartz crystals and veins. White calcite is the most abundant associate with the vein quartz in Arkansas. It is commonly intergrown with the quartz in such a way as to form a comb structure that is transverse to the vein walls. Some of the calcite occurs as rhombohedral crystals around which vein quartz was deposited; but the calcite at other localities formed thin tabular crystals that grew before or contemporaneously with vein quartz and crystal quartz. Calcite crystals showing these two habits are seldom observed but their casts are abundant at some places, especially at a locality five miles southeast of Mount Ida, Ark.

Other associated minerals in Arkansas include dickite (a clay mineral of hydrothermal origin), rectorite (a mineral related to mica), chlorite, and adularia. The dickite has been recognized at numerous places and is especially abundant as a filling material in the spaces among the crystals in the deeper mine workings. It appears to be the source of much of the surficial clays that are present in all of the crystal deposits. The rectorite fills spaces between crystals at several localities north of Jessieville, Ark. The chlorite occurs in the quartz crystals as irregular aggregates and as layers parallel with the prism and pyramid faces, thus forming phantom crystals. Adularia is known from a few localities in Arkansas, and orthoclase in minor amounts is described by C. W. Honess [2] as occurring with the vein quartz at numerous localities in McCurtain County, Okla.

Dickite is widely distributed not only in the Ouachita Mountains but also to the south and north of the main belt of vein quartz, but in these bordering areas little quartz, generally in the form of very small crystals on joint surfaces and as paper-thin veinlets, accompanies the dickite. Also some occurrences of

[2] Honess, C. W.: Geology of the southern Ouachita Mountains of Oklahoma. Oklahoma Geol. Surv. Bull. 32, pt. 1: 39–49, 1923.

dickite are known in the Oklahoma-Arkansas coal field that adjoins the north margin of the Ouachita Mountains.

Minerals of several metals that are associated with relatively small bodies of vein quartz include those of antimony near Gillham, Ark.; lead, zinc, and copper at several localities in Oklahoma and Arkansas; and mercury in the Arkansas quicksilver district. The deposits of these minerals will be discussed separately under the heading "Metalliferous mineralization."

TIME OF QUARTZ DEPOSITION.

The time of quartz deposition is inferred largely from the structural relations of the veins to the enclosing rocks and from the deformation of the veins themselves.

The deformation of the exposed rocks of the Ouachita Mountains took place during Pennsylvanian time, beginning early in this epoch and reaching its maximum near the middle of the epoch.[3] It compressed the exposed strata into a belt that measures about half the width of their original extent. From evidence here presented the closing stage of the deformation of the Paleozoic rocks was the period of quartz deposition.

The veins follow fractures and bedding planes and they may be inclined at any angle and strike in any direction. At numerous places they form a network traversing the country rock in all directions. The vein-filled fractures cut across folds in the rocks and also cut across slaty cleavage.

If much of the quartz had been deposited before or during the early stages of rock deformation, surely a large proportion of the veins would have been folded. The deformation of the veins and

[3] Honess, C. W.: *op. cit.*, p. 259.

Morgan, G. D.: Geology of the Stonewall, quadrangle. Oklahoma Bur. Geol. Bull. 2: 19–21, Norman, Okla., 1924.

Powers, Sidney: Age of the folding of the Oklahoma Mountains—the Ouachita, Arbuckle, and Wichita Mountains of Oklahoma and the Llano-Burnet and Marathon uplifts of Texas. G. S. A. Bull. 39: 1047–1049, 1928.

Miser, H. D.: Carboniferous rocks of Ouachita Mountains. A. A. P. G. Bull. 18: 1007–1009, 1934.

Harlton, B. H.: Stratigraphy of the Bendian of the Oklahoma salient of the Ouachita Mountains. A. A. P. G. Bull. 22: 861–864, 1938.

crystals is confined to faulting, fracturing, and crushing, some, if not all, of which appears to be related to a regional deformation of the rocks that included moderate folding and faulting. Such deformation in the Ouachita Mountains is not known to have taken place after Pennsylvanian time.

Some veins in laminated sandstone have been offset by shearing along the laminæ; some have been cut by faults and thus display slickensides; and some have been formed in two sets, the later one crossing the earlier one. In addition, some veins have been crushed into coarse and fine breccia in whose spaces a later generation of quartz grew. Quartz crystals by the hundreds have been noted that have been broken away from their attachment and have grown by the addition of further quartz to the fractured surfaces. In fact the crystal clusters at some places have been so greatly fractured that clusters do not remain; all the crystals at such places are doubly and singly terminated and lie loose in the clay.

Many stages in the further growth of fractured crystals may be noted. These range from fractured surfaces in which little quartz has been added, to surfaces that are nearly or completely obliterated by further growth. The new growth on such surfaces has the same crystallographic orientation as that of the original crystal. Some crystals have been bent into curved shapes through fracturing and subsequent healing of the fractures by new quartz. Crystals displaying all the features just enumerated have been observed at many localities in western Arkansas.

In addition, the crystal clusters from some localities have been torn away from the wall rock and broken into segments which lie loose in the associated clay. Such clusters, like the single crystals, reveal the subsequent addition of quartz on the fractured surfaces.

Further evidence that the veins were not formed prior to mid-Pennsylvanian time is provided by the absence of a notable quantity of locally-derived quartz in the several beds of conglomerate that occur through the sequence of Paleozoic rocks. Some of these conglomerates lie above unconformities. The thickest conglomerate, which is at the base of the Hot Springs sandstone

(Pennsylvanian), has a maximum thickness of 35 feet and contains no quartz pebbles. Those of pre-Pennsylvanian age are thinner, none of them exceeding 10 to 12 feet in thickness. They all contain pebbles of locally-derived rocks but a few contain quartz pebbles, and these pebbles are believed to have had a foreign source similar to that of some of the associated clastic material.

That the veins were not formed as late as Cretaceous time is also shown by (1) the absence of quartz veins in the strata of Lower and Upper Cretaceous age that are widely exposed near the Ouachita Mountains, (2) the great quantity of locally-derived quartz pebbles and cobbles in the many Cretaceous gravel beds near these mountains, and (3) the fact that at two localities in Saline County, Ark., to be described later, Cretaceous igneous dikes are clearly later than the quartz veins.

ORIGIN OF QUARTZ.

The hydrothermal origin of the quartz veins and crystals in Arkansas is shown by the occurrence in them of contemporaneously formed dickite, platy calcite, and adularia. The quartz veins in Oklahoma, which contain orthoclase as a common constituent and much calcite and siderite, are believed by Honess [4] to be hydrothermal but in part to be pegmatites.

The solutions, from which these minerals were deposited, were probably of magmatic origin, and thus came from deep-lying igneous rock magma that moved upward toward the surface in the geosynclinal area during the Pennsylvanian orogeny. No igneous rocks of this age are exposed in the Ouachita Mountains except possibly two small diorite dikes in McCurtain County, Okla. The nephelite syenites and related types of rocks that are exposed at many places in Arkansas are all believed to be of Cretaceous age. These igneous rocks in Arkansas and Oklahoma and their relation to the quartz veins of the Ouachita Mountains will be described briefly under a later heading.

[4] Honess, C. W.: op. cit., pp. 39–40, 48–49, 210, 261. Geology of Atoka, Pushmataha, McCurtain, Bryan, and Choctaw Counties. Oklahoma Geol. Surv. Bull. 40–R: 11, 1927.

In the long ascent of the hydrothermal solutions from their magmatic source, their character doubtless changed owing to loss of temperature and to contact with other solutions. They thus probably deposited a part of their load en route and picked up some substances before reaching the present exposed rocks which were then, of course, deeply buried; in fact, a part of the substances in the quartz veins may have been derived from the rocks traversed by the solutions or from rocks enclosing the veins—quartz from the sandstones, calcite from the limestones, and potash and alumina for the adularia from the slates.

Although the hydrothermal solutions deposited quartz and dickite in greater or lesser amounts in all parts of the Ouachita Mountains, they were most active in the main quartz-bearing belt extending west-southwest from Little Rock (Fig. 2). To account for the restriction of most of the quartz to this belt the suggestion is offered that the regional arching of the strata to form the anticlinorium of the Ouachita Mountains was a final stage in the deformation of the depositional geosyncline of these mountains. Such regional upwarping would have developed tensional fractures to serve as suitable sites for growth of the quartz, and continued upwarping during the period of quartz deposition would have produced brecciation and fractures that would be healed partly or wholly by later deposition of quartz. Again such an arching of the strata would have brought strata, once deeply buried, closer to the surface than they are in the areas bordering the anticlinorium. Thus, the strata now exposed in the anticlinorium may have been at higher temperatures at the time of quartz-vein formation than strata in adjoining belts because of greater depth of burial.

Such a structural warping would break the slates, cherts, sandstones, and quartzites alike but on the other hand would break the shales less readily. All these kinds of rocks were traversed by quartz-depositing waters in the central part of the main anticlinorial belt of the Ouachitas, but both to the south and north away from this central part the quartz-depositing solutions were largely confined to sandstones and rarely penetrated shales.

Thus the whole quartz-vein belt was permeated by hydrothermal solutions and their heat was doubtless responsible to some degree for the metamorphism of certain rocks like sandstone and the novaculite, but the slates, as previously stated, had been formed by differential pressure and heat before the introduction of the quartz. The areas of dickite and minor quartz both to the north and south of the main belt of quartz veins were also permeated by thermal waters which were presumably not so warm as those of the central belt.

That hydrothermal solutions were capable of producing metamorphic changes is suggested by evidence provided by the hot springs at Hot Springs, Ark. At that place the springs issue from the southwest end of Hot Springs Mountain and there the heat from the water appears to have transformed the Arkansas novaculite, a variety of chert, into a rock resembling fine-grained quartzite of considerably coarser texture than that on other parts of the mountain and elsewhere in the vicinity.[5] The fractures through which the hot springs issue are partly to completely filled with calcite and quartz, including comb quartz.[6] Apparently the calcite and quartz at this locality, which is thus marked by recent locally intense metamorphism, have been deposited by the hot waters after the quartz deposition in Pennsylvanian time.

RELATION OF QUARTZ VEINS TO METAMORPHISM OF ROCKS.

The structural deformation of the rock sequence, 25,000 feet thick, must have taken place when the present exposed rocks were underneath great cover, the greatest cover being above the rocks exposed in the anticlinorium. The folding and faulting, combined with heat from depth of burial and friction during deformation, changed the rocks physically and chemically.

The quartz veins, being most numerous and widest in a belt along the main anticlinorial axis of the Ouachita Mountains, are

[5] Purdue, A. H., and Miser, H. D.: Description of the Hot Springs district. Geologic Atlas of the United States, Hot Springs folio, No. 215, p. 5, 1923.

[6] Burchard, E. F.: Oral communication.

Bryan, Kirk: The hot water supply of the hot springs, Arkansas. Jour. Geol. 30: 437, 1922.

in general confined to the oldest rock strata, which in general are most metamorphosed. The pre-Pennsylvanian shales in the quartz-vein belt and the basal portion of the Stanley shale in this belt have been changed to slates, some of which show differently colored ribbon-like bands on cleavage surfaces that cut across the bedding. Also in this belt the Jackfork sandstone has been more affected by metamorphism than in the areas to the north and south. Another noteworthy relation is that north of Broken Bow, Okla., and in a large area southwest of Little Rock, not only are the quartz veins in general thicker than elsewhere but the Jackfork sandstone and all the older rocks have undergone more metamorphism than they have in other parts of the quartz vein-bearing belt. Here the Ordovician slates are more schistose than elsewhere; the Stanley shale as a whole is more slabby, harder, and blacker on exposed surfaces than elsewhere; and the Arkansas novaculite has become a rock resembling fine-grained quartzite.

Rocks of the same age and same original character as those of the quartz vein-bearing belt are exposed in and near Black Knob Ridge at the west end of the Ouachita Mountains, and in and near the Potato Hills in their northwestern part. The rocks in these two areas are not traversed by quartz veins nor are they metamorphosed like those of the main vein-belt. Here the shales of pre-Pennsylvanian age have not been changed to slates and the sandstones and shales of Pennsylvanian age are still ordinary shales and sandstones.

To test these conclusions, specimens of Jackfork sandstone and the Arkansas novaculite were collected from all parts of the Ouachita Mountains for petrographic examination. This examination, which has been made by Robert P. Bryson, consisted of a study of specimens of Jackfork sandstone from 29 localities and of Arkansas novaculite from 24 localities. It has disclosed that these two formations have been subjected to varying degrees of metamorphism, increasing in intensity toward the main anticlinorial axis of the Ouachita Mountains and reaching a maximum in two areas along this axis, one north of Broken Bow, Okla., and the other southwest of Little Rock (Fig. 3).

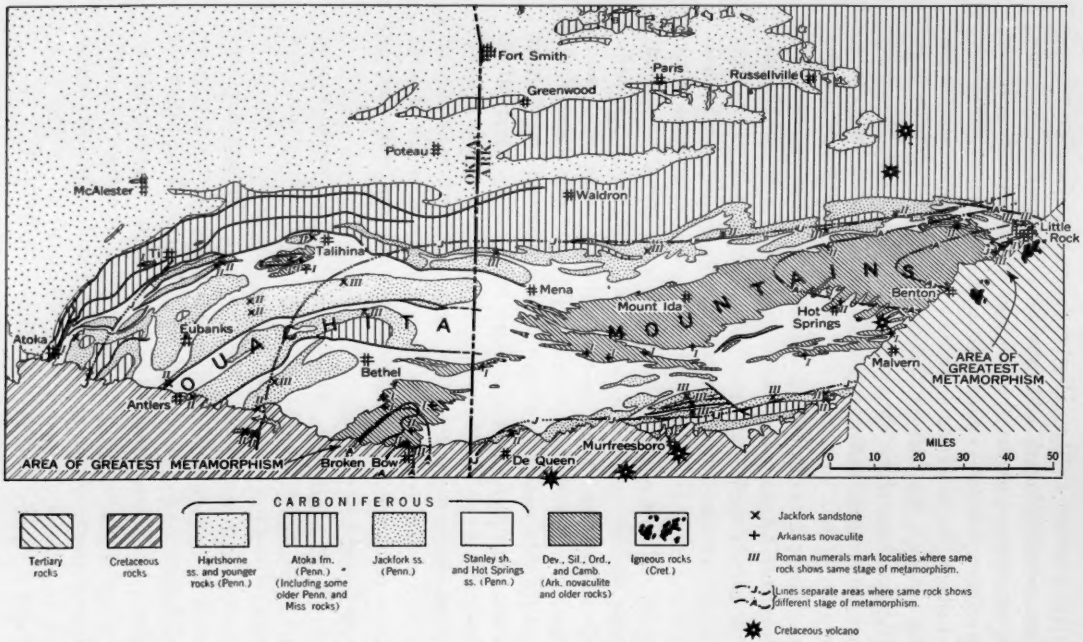

FIG. 3. Geologic map of Ouachita Mountains and parts of adjoining regions, Arkansas and Oklahoma, showing, by Roman numerals, progressive regional metamorphism of Jackfork sandstone and Arkansas novaculite. Based on study of thin sections of specimens from indicated localities. Higher numerals indicate greater metamorphism. For explanation of numerals see pages 105, 106.

The progressive metamorphism of the Jackfork sandstone has resulted in marked changes, namely, (1) the formation of less regular boundaries between the sand grains, (2) the formation of sutures along the contacts between the grains, and (3) the transformation of the interstitial material into coarser-grained material, with the development of new quartz grains, mica, and chlorite. These changes have thus transformed the texture of the Jackfork sandstone to the mosaic texture of a quartzite in parts of the area. The specimens of the sandstone from the different localities have been classified by Mr. Bryson into four groups, designated (by Roman numerals) below and on Figs. 3 and 5, on the basis of the progressive changes recognized during his microscopic examination of thin sections of the specimens. A brief description of these four groups follows:

I. Rounded sand grains; grain boundaries showing no effect on individual grains of their impingement on adjacent ones.

II. Rounded to angular sand grains; some grain boundaries modified by impingement on adjacent sand grains; some small amount of recrystallization of interstitial material to make new quartz, chlorite, and mica.

III. Angular sand grains; many grain boundaries modified and sutures developed on contacts between (*a*) adjacent original sand grains, (*b*) new grains of quartz formed by the partial recrystallization of the interstitial material and (*c*) original and new grains.

IV. Mosaic of angular grains with sutured boundaries, resulting from modification of the original sand grains and recrystallization of the interstitial material to make new quartz, chlorite, and mica.

Progressive metamorphism of the Arkansas novaculite has resulted in the destruction of original sedimentary textures and in an increase in grain size. It has caused the disappearance of radiolaria, detrital quartz grains, and grains of rhombohedral calcite and of chalcedony, present in the original novaculite. In addition, dynamic metamorphism has produced fracturing and

shearing and preferred orientation of the grains in some of the specimens. The specimens of the novaculite, like those of the Jackfork sandstone, have been classified by Mr. Bryson into four groups designated (by Roman numerals) below and on Figs. 3 and 5, on the basis of their microscopic features. A description of the four groups is here given:

I. Fine-grained (less than 0.01 mm.) novaculite; variable grain size; radiolaria, chalcedonic grains, detrital quartz sand grains, and rhombohedral grains of calcite are preserved in the specimens from many localities; quartz veins may be present.

II. Fine- to medium-grained novaculite; radiolaria and chalcedonic grains not preserved; detrital quartz grains show boundary changes; rhombohedral grains or casts of calcite may remain; quartz veins common.

III. Medium-grained novaculite; detrital quartz and rhombohedral grains or casts of calcite not preserved; quartz veins common.

IV. Coarse-grained (more than 0.03 mm.) novaculite.

The oilstone quarries in the Arkansas novaculite near Hot Springs, Ark., are in an area in which this formation has been metamorphosed to some extent, generally more so than elsewhere in the Ouachita Mountains except in the part of the mountains a few miles north of Broken Bow, Okla.

The porosity of the Paleozoic sandstones of Arkansas, as shown by G. C. Branner,[7] bears a general relation to the degree of their deformation and metamorphism. In the Ouachita Mountains the average porosity of sandstones of different ages is 5.7 per cent; in the western Arkansas coal field, an area of little metamorphism and moderate deformation, it is 7.8 per cent; and in the Ozark region, where the rocks have been changed and deformed very little, it is 10.9 per cent.

[7] Branner, G. C.: Sandstone porosities in Paleozoic region in Arkansas. A. A. P. G. Bull. 21: 67–78, 1937.

METAMORPHISM OF GRAHAMITE DEPOSITS.

Grahamite deposits occur in the frontal part of the Ouachita Mountains, chiefly in Oklahoma. They lie northwest of the areas of the more metamorphosed rocks of the region and also northwest of the main zone of quartz veins (Figs. 4 and 5). They occur as veins and irregular bodies in Pennsylvanian and older rocks. The percentage of fixed carbon of the grahamite from Sardis, Okla., where the largest known body, 100 yards long, 50 to 100 feet wide, and 2 to 30 feet thick, has been mined, is 53.4 [8] and that of the grahamite from Impson Valley is 55.97. According to J. A. Taff,[9] the deposits containing the highest percentages of fixed carbon occur in Black Fork Mountain, Okla., and in Fourche Mountain, Ark., where these percentages are 75.90 and 79.15, respectively. The variation in composition has been attributed by Taff to differences in the degrees of metamorphism, the progressive change brought about by the loss of the more volatile hydrocarbons.

METAMORPHISM OF COALS.

The coals of the southeastern Oklahoma-western Arkansas coal field, which lies alongside the north margin of the Ouachita Mountains, show from west to east progressive metamorphism from high volatile bituminous through medium- and low-volatile bituminous coals to semianthracite (Fig. 4). The coal beds occur in the Hartshorne and younger Pennsylvanian rocks which succeed the Atoka formation, the youngest Pennsylvanian formation in the Ouachita Mountains. The percentages of fixed carbon, as shown by the isocarb line map of T. A. Hendricks,[10] range progressively from about 50 near Atoka, Okla., at the west of the field, to about 88 near Russellville, Ark., at the east end of the field. This eastward increase of fixed carbon in the coals is ac-

[8] Stadnichenko, Taisia: Oral communication.

[9] Taff, J. A.: Grahamite deposits of southeastern Oklahoma. U. S. Geol. Surv. Bull. 380: 296–297, 1909.

[10] Hendricks, T. A.: Carbon ratios in part of Arkansas-Oklahoma coal field. A. A. P. G. Bull. 19: 937–947, 1935.

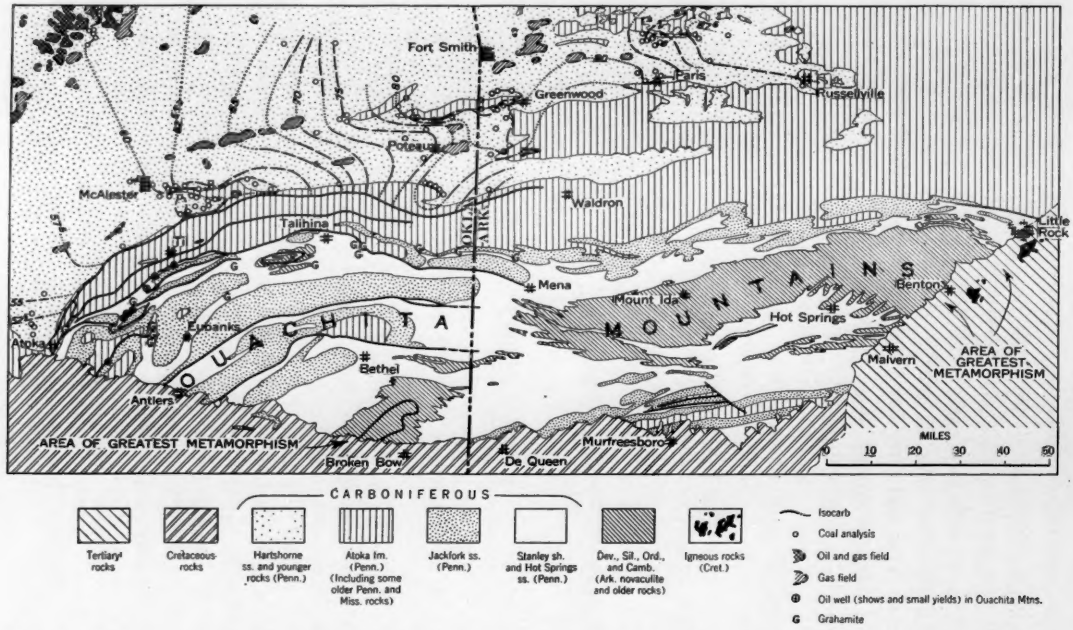

FIG. 4. Geologic map of Ouachita Mountains and parts of adjoining regions, Arkansas and Oklahoma, showing carbon ratios of coals, grahamite deposits, and oil and gas fields.

companied by an increase in the fixed carbon in the grahamite of the Ouachita Mountains.

The coals in Oklahoma lie closer to the Ouachita Mountains than the coals in Arkansas, owing in part to the southward disappearance of the coals in the coal measures in Arkansas, so that the southernmost exposures of coal-measures rocks there do not contain workable coals. The coal-bearing rocks in Oklahoma, on the other hand, contain coals in their southernmost exposures. Also the closer proximity of the Oklahoma coal field to the Ouachita Mountains appears to be due in part to a greater northward thrust of the rocks of the Ouachita Mountains in that State than in Arkansas. The arcuate frontal margin of the overthrust sheets of the Oklahoma part of the Ouachita Mountains thus adjoins the area of coals containing the lowest percentages of fixed carbon. In spite of this overthrusting, the axis of the main anticlinorium of the Ouachita Mountains in Oklahoma lies farther south, away from the coal field, than it does in Arkansas (Fig. 4). A corollary to this is that the coals with the lowest carbon ratios in Oklahoma lie farther away from the quartz-bearing metamorphosed rocks of the Ouachita Mountains than do the coals with the higher carbon ratios in Arkansas (Fig. 5).

The isocarb lines in the coal field reveal many irregularities, some of which are due to high carbon ratios on some anticlines, notably the Backbone and McAlester anticlines. In such localities the high carbon ratios were produced by locally intense structural deformation. Then, in the southern part of the Arkansas coal field the carbon ratios decrease in general toward the south and thus in the direction toward which the deformation of rocks increases. This change is anomalous, provided the metamorphism of the coal be attributed largely to the degree of deformation produced by pressure from the south. To explain it, Hendricks [11] suggests that the southward decrease in carbon ratios in Arkansas may be due to downwarping of the coal field as a result of compensation during the upwarping of the Ouachita anticlinorium.

[11] Hendricks, T. A.: Oral communication.

The postulated downwarping followed the major period of deformation and metamorphism of the coal field just as the upwarping of the Ouachita anticlinorium followed such a period in the Ouachita Mountains. The axis of this downwarp lay along the south side of the coal basin, so in effect the coal basin was tilted southward; and, later, after post-Paleozoic planation, beds that were deepest at the time of major metamorphism became exposed in the northern part of the coal field. Being deeper, those beds were more metamorphosed and the apparent areal relationship actually is a function of depth.

Another important factor in coal metamorphism in the Oklahoma-Arkansas field may, as has been suggested by D. J. Fisher,[12] be heat from an outside source. It has already been noted that the degree of metamorphism of the rocks of the Ouachita Mountains is related in part to structural deformation but also in part to heat. Some of the heat there resulted from depth of burial and from friction during deformation; but some of the heat, as witnessed by the veins of quartz and other minerals, was introduced upward from deep-lying sources. In the part of the Ouachita Mountains adjoining the coal field, dickite and minor quartz were widely distributed, and some occurrences are known in the coal field in eastern Oklahoma and western Arkansas. These occurrences testify to heat that was transferred upward by hydrothermal solutions into the coal-bearing rocks.

RELATION OF EXPOSED IGNEOUS ROCKS TO QUARTZ VEINS AND REGIONAL METAMORPHISM.

Igneous rocks of Cretaceous age are widely exposed in and near the Ouachita Mountains in western Arkansas, and two dikes of Paleozoic age are exposed in the mountains in northern McCurtain County, Okla. Because these occur in areas that have been subjected to varying degrees of regional metamorphism and because they occur near areas of mineral deposits whose origin has

[12] Fisher, D. J.: Carbon ratios north of the Ouachitas. A. A. P. G. Bull. 20: 102–105, 1936.

been related by some geologists [13] to them, a brief discussion of the relations of the igneous rocks to the quartz veins and to regional metamorphism is appropriate at this point.

The igneous rocks of Arkansas include exposures of nephelite syenites and related types at four localities, Little Rock, Bauxite, Magnet Cove, and Potash Sulphur Springs (Fig. 2). Also, they include many hundreds of dikes, several areas of peridotite, and six volcanic necks which are located as follows: The peridotite area at the mouth of Prairie Creek near Murfreesboro [14]; two postulated concealed necks [15] (between Murfreesboro and Nashville on Fig. 3)—one, a few miles northwest of Nashville, the other just south of Lockesburg; two localities near Perryville [16]; and Magnet Cove.[17] The igneous rocks of all these bodies have been injected into the Paleozoic strata of the region, the youngest being the Atoka formation of early Pennsylvanian age.

The volcano at Murfreesboro, as shown by the relations of the peridotite to the Lower and Upper Cretaceous rocks, was active in early Upper Cretaceous time. The postulated volcanoes near Nashville and Lockesburg were also active at this time and provided a vast quantity of tuff and ash that was spread widely and deposited in the Woodbine and Tokio formations of Upper Cretaceous age in Arkansas, Oklahoma, and Texas. The ejected material from the Lockesburg and Nashville volcanoes has been shown by C. S. Ross [18] to be similar to the rare alkaline rock types at Little Rock, Bauxite, Magnet Cove, and Potash Sulphur

[13] Hess, F. L.: The Arkansas antimony deposits. U. S. Geol. Surv. Bull. 340: 251–252, 1908.

Branner, G. C.: Cinnabar in southwestern Arkansas. Arkansas Geol. Surv. Inf. Circ. 2: 28, 1932.

[14] Miser, H. D., and Ross, C. S.: Diamond-bearing peridotite in Pike County, Ark. U. S. Geol. Surv. Bull. 735: 279–322, 1923.

[15] Ross, C. S., Miser, H. D., and Stephenson, L. W.: Water-laid volcanic rocks of early Upper Cretaceous age in southwestern Arkansas, southeastern Oklahoma, and northeastern Texas. U. S. Geol. Surv. Prof. Pap. 154: 189–191, 1929.

[16] Croneis, Carey, and Billings, Marland: New areas of alkaline igneous rocks in central Arkansas. Jour. Geol. 37: 542–561, 1929.

[17] Ross, C. S.: Titanium deposits of Nelson and Amherst Counties, Virginia. U. S. Geol. Surv. Prof. Pap. 198: 23–26, 1941.

[18] Ross, C. S., Miser, H. D., and Stephenson, L. W.: op. cit., pp. 187–188.

Springs. Also the breccias in volcanic necks near Perryville (between Russellville and Little Rock on Fig. 3) contain, according to Carey Croneis and Marland Billings,[19] rock types similar to those of the four different areas just mentioned. The occurrence of these types of rocks at many places within a relatively small area measuring 125 miles in its longest dimension supports the conclusion that all of them were formed during the same period of igneous activity and are thus of Cretaceous age.

Igneous activity of early Upper Cretaceous time also took place in other States, including Texas, Louisiana, and Mississippi. It was contemporaneous with the initial downwarping of the Mississippi embayment, which followed a land period and truncation [20] by erosion of 10,000 feet of Lower Cretaceous and Jurassic sediments in the lower part of the present embayment area. This igneous activity thus accompanied the most important structural event in the Gulf Coastal Plain that has taken place since the Jurassic subsidence and submergence of the Paleozoic land Llanoria of Louisiana and eastern Texas.

Near Glover, Okla. (northwest of Broken Bow), a diorite sill, 2 to 10 feet wide, and also a nearby undescribed diorite dike have been intruded into Ordovician rocks and have thus been assigned an Ordovician or later age by Honess.[21] Although the diorite has been fractured to bits by structural deformation, it may have been intruded as late as the time of structural deformation in the Pennsylvanian.

The contact metamorphism produced by the dikes and sills in Arkansas and Oklahoma is not great. At most places there is no noticeable change in the wall rocks and at other places the changed character of the wall rocks does not extend more than a few feet from the igneous bodies. The contact-metamorphic zone around the larger igneous rock bodies is generally less than half a mile

[19] Croneis, Carey, and Billings, Marland: op. cit., pp. 542–561.

[20] Weeks, W. B.: South Arkansas stratigraphy with emphasis on the older coastal plain beds. A. A. P. G. Bull. 22: 953–983, 1938.

Imlay, R. W.: Lower Cretaceous and Jurassic formations of southern Arkansas and their oil and gas possibilities. Arkansas Geol. Surv. Inf. Circ. 12, 1940.

[21] Honess, C. W.: Geology of the southern Ouachita Mountains of Oklahoma. Oklahoma Geol. Surv. Bull. 32, pt. 1: 210–212, 261, 1923.

wide and within it sandstones have been changed to quartzites, shales to hard, generally massive rock, and novaculite to a rock resembling fine- to coarse-grained quartzite. As these metamorphosed rocks are followed away from the intrusive bodies they show a gradual change to the normal rocks of the locality.

Quartz veins and crystals that are demonstrably related in origin to these igneous rocks are not abundant and occur at few localities. At the diamond mines near Murfreesboro, Ark., chalcedonic and crystalline quartz, both amethystine and white, occurs as rare veins as much as 4 inches wide in the peridotite breccia in the neck of an early Upper Cretaceous volcano. Also in an area of contact metamorphism along the east margin of the exposure of nephelite syenite and other igneous rocks at Magnet Cove, smoky quartz crystals are relatively abundant.

As has been pointed out already, the Cretaceous igneous rocks are later than the quartz veins that are so widespread and abundant in the Ouachita Mountains. This relationship is clearly shown at two localities, both in Saline County, Ark. (between Hot Springs and Benton), where quartz veins like those in other parts of the Ouachita Mountains are in contact with dikes related to the syenitic rocks. At the abandoned fuller's earth mines, 7 miles west of Benton, the fuller's earth is a decomposition product of dikes of igneous rock.[22] The veinlike bodies of fuller's earth cut across quartz veins and several small feeders of dike-derived material were observed to extend away from the main dikes and occupy fissures alongside quartz veins. Also at a quartz-crystal mine near the west line of the county and north of U. S. Highway 70 a dike of igneous rock now altered to earth came upward adjacent to a mass of white quartz 85 feet long and 25 feet wide and flowed around and enclosed quartz crystals as much as 2 feet or more in length. The crystals thus enclosed in the igneous rock display the unusual feature of exfoliation and peeling in layers like an onion. Obviously the peeling may be attributed to strains or cracks produced by the temperature of the igneous dike. The

[22] Miser, H. D.: Developed deposits of fuller's earth in Arkansas. U. S. Geol. Surv. Bull. 530: 210–216, 1912.

quartz crystals in the deposits away from the dike are normal crystals, lacking this exfoliated character.

METALLIFEROUS MINERALIZATION.

Deposits of metalliferous minerals, including those of antimony, lead, copper, zinc, and mercury, are found at places in the Ouachita Mountains and, although they are associated with more or less quartz, the amount of quartz with them is generally very much less than that of the larger veins of the region (Fig. 5). Some geologists [23] have connected the origin of these metalliferous minerals with the Cretaceous igneous rocks, but others,[24] among whom I may be counted, believe that the metalliferous deposits and their associated minerals may be related to the period of Pennsylvanian structural deformation.

Concerning the origin of the mineral deposits in the Oklahoma part of the Ouachita Mountains, Honess expresses the following opinions: "As the folding of the mountains progressed, intrusions occurred. Among the deposits introduced at this time (middle Pennsylvanian) in Oklahoma are: (1) lead, zinc, and copper sulphides in a quartz-carbonate gangue; (2) large quartz veins and quartz-orthoclase pegmatites." [25] In his description of the lead, zinc, and copper deposits in that area [26] he recognized as many as three periods of brecciation of the vein and wall rocks. This number of periods of brecciation corresponds to the number of periods of fracturing of the quartz recognized by a veteran miner of quartz crystals in the Crystal Mountains of Arkansas.

[23] Hess, F. L.: The Arkansas antimony deposits. U. S. Geol. Surv. Bull. 340: 251–252, 1908.

Branner, G. C.: Cinnabar in southwestern Arkansas. Arkansas Geol. Surv. Inf. Circ. 2: 28, 1932.

[24] Honess, C. W.: Communication of May 15, 1932, quoted in Branner, G. C., Cinnabar in southwestern Arkansas. Arkansas Geol. Surv. Inf. Circ. 2: 28, 1932.

Stearn, N. H.: Discussion of Tech. Pub. 612. A. I. M. E., Trans. 115: 244–246, 1935.

Reed, J. C., and Wells, F. G.: Geology and ore deposits of the southwestern Arkansas quicksilver district. U. S. Geol. Surv. Bull. 886: 51–53, 1938.

[25] Honess, C. W.: op. cit.

[26] Honess, C. W.: Geology of the southern Ouachita Mountains of Oklahoma. Oklahoma Geol. Surv. Bull. 32, pt. 2: 35–42, 1923.

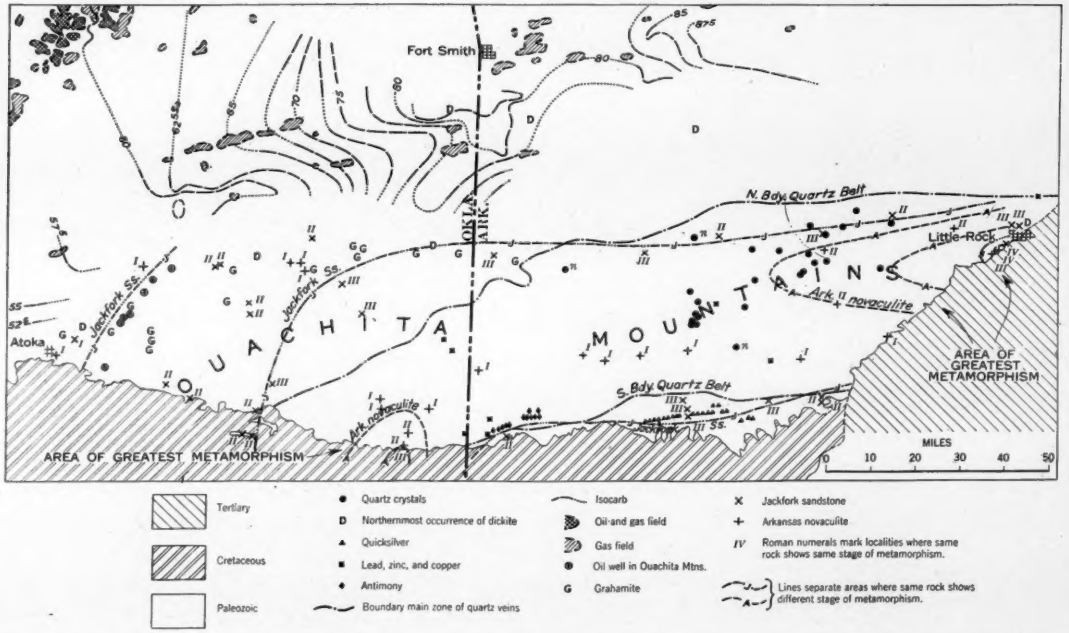

FIG. 5. Map of Ouachita Mountains and parts of adjoining regions, Arkansas and Oklahoma, showing relation of occurrence of quartz veins to other mineral deposits and to regional metamorphism.

n at quartz locality denotes negative crystals. For explanation of Roman numerals see text.

Lead, zinc, and copper sulphides occur at several places in Arkansas, some of which are near Gillham and thus near the Oklahoma deposits. Also near Gillham are antimony deposits and farther east in Pike and Clark Counties are quicksilver deposits. N. H. Stearn[27] and later John C. Reed and Francis G. Wells,[28] on the basis of structural deformation including some faulting during and subsequent to mineralization, have expressed the conclusion that the quicksilver deposits are more likely late Paleozoic than Upper Cretaceous, the time of igneous activity in Arkansas. Furthermore, the presence of stibnite in the quicksilver deposits suggests a genetic relation between the quicksilver deposits and those of antimony, lead, and zinc to the west. As stated by Reed and Wells, "it seems probable that the cinnabar, antimony, and lead-zinc deposits were formed during the same period of ore deposition, because they all occur in the same formations, occupy structural features formed by the same diastrophism, and have related mineral assemblages."

The postulated Pennsylvanian mineralization in the Ouachita Mountains may have been accompanied by metalliferous mineralization elsewhere in the Mississippi Valley, for the geologic processes including the structural deformation that affected the Ouachita area probably affected a much larger area—the Ozark region and other parts of the Mississippi Valley. The suggestion is thus offered here that the period of quartz deposition during the closing stage of the Pennsylvanian orogeny in the Ouachita Mountains may have been accompanied by the presence of hydrothermal solutions in the Batesville manganese district of the Ozark region, in northeast-central Arkansas.[29] These thermal solutions were responsible for the concentration of finely disseminated manganese carbonate in the Fernvale limestone (Ordovician) into bodies containing rhodochrosite, hausmannite, braunite, bementite, and neotocite.

There are many opinions concerning the origin of the lead and

[27] Stearn, N. H.: op. cit.

[28] Reed, J. C., and Wells, F. G.: op. cit., pp. 44 and 51–53.

[29] Miser, H. D.: Manganese carbonate in the Batesville district, Ark. U. S. Geol. Surv. Bull. 921: 1–94, 1941.

zinc deposits of northern Arkansas and the tri-State district,—southwestern Missouri, southern Kansas, and northeastern Oklahoma—and other parts of the Mississippi Valley region. One of them is that the ore deposits were deposited by hydrothermal solutions of magmatic origin. Some writers on the Mississippi Valley region, who have expressed opinions concerning the dating of the lead and zinc deposition from magmatic sources, have attempted to relate the deposits to the Cretaceous igneous activity of Arkansas and other States.[80] The suggestion here offered is that the sponsors of the theory of magmatic origin consider the possibility that the metalliferous mineralization in the Mississippi Valley region took place at the time of the Pennsylvanian quartz deposition in the Ouachita Mountains.

SUMMARY STATEMENT.

Each geologic feature of an area, whether it be a quartz-vein crystal, an anticlinorium, a grahamite deposit, a coal bed, an igneous rock, or a metalliferous deposit, is related to all the other geologic features of that area. The full narration of the geologic history of an area is, in reality, a fascinating connected story in which each and every geologic feature plays a part. An important chapter of the geologic history of the Ouachita Mountains is that revealed by the quartz veins and crystals. Some of the highlights of that chapter will now be briefly summarized.

The quartz veins and crystals and their associated minerals are hydrothermal deposits of probable magmatic origin. They were formed during the closing stage of the mid-Pennsylvanian orogeny that deformed the thick Paleozoic sequence of the Ouachita Mountains. At this time metamorphic changes of the rocks were produced by dynamic movement and heat to which was added the heat of the hydrothermal solutions. These processes produced varying degrees of metamorphic changes in the rocks not only throughout the Ouachita Mountains but also in the adjoining coal field of

[80] Bastin, E. S., and Behre, C. H., Jr.: Origin of the Mississippi Valley lead and zinc deposits—a critical summary in Bastin, E. S., Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley region. G. S. A. Spec. Pap. 24: 121–143, 1939.

southeastern Oklahoma and western Arkansas. The belt of greatest metamorphism lies along the axis of the main anticlinorium of the Ouachita Mountains and this belt contains not only the largest exposures of pre-Pennsylvanian rocks but also most of the vein quartz. The regional arching of the strata to form the anticlinorium apparently followed the major structural deformation and metamorphism of the strata of the depositional geosyncline of the Ouachita Mountains. Such a regional upwarping would have brought strata, once deeply buried and thus having relatively higher temperatures, closer to the surface than they are in the areas bordering the anticlinorium. The upwarping apparently developed the tensional fractures through which the hydrothermal solutions passed and deposited the quartz and other minerals of the quartz veins. The metalliferous deposits of the Ouachita Mountains—those of lead, zinc, antimony, and quicksilver—appear to have been formed at the time of quartz vein deposition. The time of quartz deposition should also be considered in the dating of lead and zinc mineralization in other areas of the Mississippi Valley region.

The several geologic problems that have been discussed in the foregoing address are trails along which I have been led by my hobby, the collection of Arkansas quartz crystals. The delivery of this address today does not mean that I shall now stop and dismount from my hobby. Instead, I intend to continue the collection of Arkansas quartz crystals as long as I am an Arkansas traveler and can obtain funds and credit for the purchase of quartz crystals from the dealers occupying the roadside stands in western Arkansas.

In the preparation of this address I am indebted to Mr. Bryson, who has made a petrographic study of my specimens of Arkansas novaculite and Jackfork sandstone, to Messrs. C. S. Ross and W. T. Schaller, who have identified the minerals associated with the quartz, and Messrs. Ross, E. T. McKnight, and T. A. Hendricks, who have read critically my manuscript and offered suggestions.

WASHINGTON, D. C.,
October 14, 1942.

NOTES ON THE EARLY HISTORY OF WATER-WELL DRILLING IN THE UNITED STATES.[1]

CHARLES W. CARLSTON.

ABSTRACT.

The standard cable-tool drilling rig was invented and developed in drilling salt wells in the West Virginia-Ohio-Pennsylvania region during the twenty years following the successful completion of the first drilled well in 1808 by the Ruffner brothers at the Great Buffalo Lick near Charleston, West Virginia. Some time previous to 1823, Levi Disbrow studied the drilling methods used in the western salt industry and came east to become the first professional water well driller in the states north of the Potomac River.

Possibly the first artesian water well in the United States was constructed in 1820 in Charleston, South Carolina, by sinking an iron pipe through a clay bed. Auger boring for artesian water appears to have been first used in Charleston, South Carolina, in 1823; however, the first successful auger-bored well was not completed in that city until after 1825. The drilling methods and tools were copied from a description of a well bored in London, England.

Between 1821 and 1833 auger boring of artesian wells began in the Black Belt of Alabama and possibly in Mississippi. The process of jetting wells, invented in 1884, became the chief method of sinking artesian wells in the Atlantic and Gulf Coastal Plain by the end of the century. The first successful artesian wells in Georgia and Florida were put down during the period 1880–1882.

INTRODUCTION.

WHILE the writer was engaged in a survey of the ground water resources of the Cretaceous area of Alabama, which was being carried out by the U. S. Geological Survey in cooperation with the Alabama State Geological Survey, he was told that the first artesian well in Alabama was drilled in Cahaba at the time that town was capital of the state, or about the year 1820. The well was supposed to have been drilled by a Frenchman. The story led to the fascinating speculation that the Frenchman was possibly

[1] Published with the permission of the Director of the U. S. Geological Survey and the State Geologist of Alabama.

a member of the famous Vine and Olive Colony of refugee French followers of Napoleon at nearby Demopolis, Alabama. The unknown Frenchman may have seen wells drilled in his native France, noticed a similarity between the Coastal Plain formations of Alabama and those of France, and thus was led to introduce well drilling into the United States as a direct importation from France.

The resultant research into the history of water well-drilling in the United States which the writer has made failed to disclose any evidence for this story and produced some evidence which indicates that it is factually unfounded. The results of the research are presented with the hope that the information contained in this paper will lead to more thorough study of a facet of our economic history which has hitherto been somewhat neglected. The tentative conclusions as to such matters as the importation of auger boring of wells from England; the date of the first tubular artesian well in the United States, and the origin of the standard drill rig should be accepted only until further research confirms or disproves them. In addition little or no information is given in this paper on the history of well drilling west of the Alleghany Mountains since 1823, and in the states north of the Potomac since 1830.

ACKNOWLEDGMENTS.

For aid during research the writer is greatly indebted to William H. Heers, Librarian of the U. S. Geological Survey; Ellen Hildreth, Librarian of the Alabama Geological Survey; and Mary R. Mullen, Librarian, Frances M. Hails, Archivist, and Peter A. Brannon, Archivist of the Alabama Department of Archives and History. The manuscript has benefited from the suggestions of O. E. Meinzer, A. G. Fiedler, and V. T. Stringfield of the U. S. Geological Survey; Stewart J. Lloyd of the Geological Survey of Alabama; and Philip H. Overmeyer of the University of Alabama. For many hours of library research and helpful constructive criticism on the manuscript, the writer is especially indebted to his wife, Catherine Ball Carlston.

THE WESTERN SALT INDUSTRY AND THE DEVELOPMENT OF THE CABLE DRILL RIG 1806–1823.

The discovery of salt licks on the Kanawha River was largely responsible for opening up the territory west of the Virginia Alleghany Mountains for immigration, and by late in the 18th century the Kanawha River salt licks were being extensively worked by white settlers. As more and more settlers filtered into the Kanawha Valley region the demand for more salt caused the brothers David and Joseph Ruffner to attempt to increase the yield of salt from the Great Buffalo Lick, located upstream from Charleston on the Kanawha River.

In 1806 the Ruffner brothers began work by sinking a "gum," or a hollow sycamore log, four feet in diameter down through the ooze and quicksand of the salt lick. By digging with pick, shovel, and crowbar inside the gum and lifting the sand out with a large bucket, the gum was slowly settled thirteen feet to an iron-cemented crust of sand and gravel. They shaped the bottom of the gum so that it would fit the irregular surface of the crust and help keep the surface water from coming into the gum.

M. F. Maury's description of the ensuing operations is worthy of repetition.

> By this means the gum was gotten sufficiently tight to be so bailed out as to determine whether the salt water came up through the rock. This turned out to be the case. The quantity welling up through the rock was extremely small, but the strength was greater than any yet gotten, and this was encouraging. They were anxious to follow it down, but how? They could not blast a hole down there under water; but this idea occurred to them: They knew that rock blasters drilled their powder holes 2 or 3 feet deep, and they concluded they could, with a longer and larger drill, bore a correspondingly deeper and larger hole. They fixed a long iron drill, with a 2½-inch chisel bit of steel, and attached the upper end to a spring pole with a rope. In this way the boring went on slowly and tediously till on the 1st of November 1807, at 17 feet in the rock, a cavity or fissure was struck, which gave an increased flow of stronger brine. This gave new encouragement to bore still further; and so, by welding increasing length of shaft to the drill from time to time, the hole was carried down to 28 feet, where a still larger and stronger supply of salt water was gotten.

Having now sufficient salt water to justify it, they decided and commenced to build a salt furnace, but, while building, continued the boring, and on the 15th of January 1808, at 40 feet in the rock and 58 feet from the top of the gum, were rewarded by an ample flow of strong brine for their furnace, and ceased boring.

Now was presented another difficulty: How to get the stronger brine from the bottom of the well, undiluted by the weaker brines and fresh water from above. There was no precedent here; they had to invent, contrive, and construct anew. A metal tube would naturally suggest itself to them; but there were neither metal tubes, nor sheet metal, nor metal workers, save a home-made blacksmith, in all this region, and to bore a wooden tube 40 feet long, and small enough in external diameter to go in the 2½-inch hole, was impracticable. What they did do was to whittle out of two long strips of wood two long half tubes of the proper size, and fitting the edges carefully together, wrap the whole from end to end with small twine. This, with a bag of wrapping near the lower end, to fit as nearly as practicable, watertight, in the 2½-inch hole, was cautiously pressed down to its place, and found to answer the purpose perfectly, the brine flowed up freely through the tube into the gum, which was now provided with a watertight floor or bottom to hold it, and from which it was raised by the simple swape and bucket.[2]

Following the completion of the Ruffner Well, drill rigs began to supplant hand digging of salt wells in West Virginia and Ohio. By 1814 wells were being drilled to depths of 475 feet or more along Duck Creek in Ohio,[3] and by 1823 the Niles Weekly Register had noted that "A person at Wheeling, Virginia, has penetrated the rock seven hundred and fifty feet in search of salt water."[4]

Further developments in the technique of drilling originated in the western salt industry. A tinner at Charleston, West Virginia, made casing by soldering together tin tubes as they were put into the wells.[5] Shortly after this, casing was made of copper and fitted with screw joints.[6] In 1831 William Morris or "Billy"

[2] Maury, M. F., quoted by David White in: Geology and occurrence of petroleum in the United States. Petroleum investigation, pt. 2 U. S. 73d Cong., H. R., Committee on Interstate and Foreign Commerce, Hearings before a Subcommittee on H. Res. 441, pp. 876–877, 1934.

[3] White, David: op. cit., p. 878.

[4] Niles Weekly Register, 24: 16, March 8, 1823.

[5] Maury, M. F., quoted by David White: op. cit., p. 877.

[6] *Ibid.*, p. 877.

Morris, a well borer, invented "slips" or "jars".[7] The term "slips" was used in salt well drilling and the synonomous term "jars" came into use in the oil industry. "Jars" are double steel links about 30 inches long with jaws that slide loosely up and down. They were placed between the heavy weighted cutting bit and the line of the auger poles. They gave the bit a rapid, free cutting fall unhampered by the slower motion of the line of auger poles above and saved the poles from the damage of falling freely. They could be used to jar the line of poles upward as well as downward when the bit became stuck in the drilling process.

LEVI DISBROW—THE FIRST WATER-WELL DRILLER 1823–1832.

Some time previous to 1823 a man named Levi Disbrow was an interested observer of salt well drilling west of the Alleghany Mountains. Disbrow recognized the practicability of these well drilling methods as means of obtaining fresh water for domestic and industrial use in the east and determined to apply the methods in that area. He drilled his first well in May, 1824, for Mr. John H. Bostwick at a distillery in New Brunswick, New Jersey. The well was located at an elevation of 40 feet above the Raritan River, and after drilling 137 feet into the Triassic sandstone and shale, a small stream of water overflowed at the surface. The drilling was continued to 175 feet, where an aquifer was reached that yielded one and one-half gallons of water a minute at three feet above the ground. The cost of this well was $425.00.[8]

The success of this well ensured Disbrow's career as a well driller. By 1832 he had drilled wells at such places as Somerville, Princeton, Jersey City, and Perth Amboy, New Jersey; New Hope and Philadelphia, Pennsylvania; Baltimore, Maryland; Alexandria, D. C. (now Virginia); Harper's Ferry, Virginia (now West Virginia); Albany, Troy, and Watertown, New

[7] *Ibid.*, p. 877.

[8] [Disbrow, Levi]: An essay on the art of boring the earth for the obtainment of a spontaneous flow of water with hints toward forming a new theory for the rise of waters. Rutgers Press, 1826. Pp. 6, 7.

York; Springfield and Boston, Massachusetts (30 wells at Boston); Providence, Rhode Island (8 or 10 wells at Providence); and at least five wells in New York City.[9]

Information on Levi Disbrow's technique in drilling has fortunately been preserved through two of three patents taken out by him in 1825 and 1830. The first patent, entitled "Boring for Water," was issued March 24, 1825. The second and third

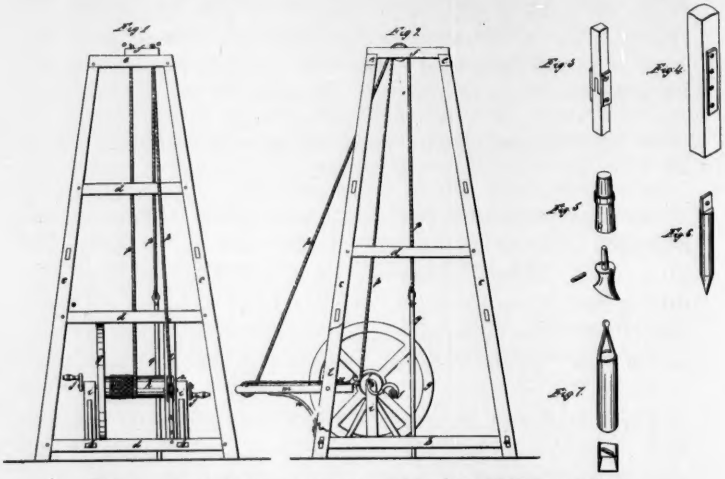

FIG. 1. Levi Disbrow's patent of Mar. 24, 1825 for drilling artesian wells.

patents were entitled "Boring for Water," and "Apparatus for Boring Earth for Water," both of which were issued November 1, 1830. The patent entitled "Boring for Water" of the date 1830 was probably destroyed by fire at the Patent Office.

The 1825 patent (Fig. 1) shows the character of the drilling rig and its hand-turned windlass. The tools marked 5 and 6 are primitive bits which were used to chip at the rock in the drill

[9] *Ibid.*, pp. 7–14.

Disbrow, Levi and Sullivan, J. L.: Advertisement of a proposition for ward companies, to supply the city of New York with rock water, etc. Clayton and Von Norden, New York, 1932. Pp. 5, 6.

hole by raising and dropping the drill stem. A sand bailer is marked no. 1 in the sketch. The bailer was lowered into the hole and forced into the sand and rock that had been loosened by the pounding action of the bits. Raising of the filled bailer automatically closed the trap at the bottom and the bailer could then be pulled up with its load of material.

Figure 2 shows the improved drilling rig as patented by Disbrow

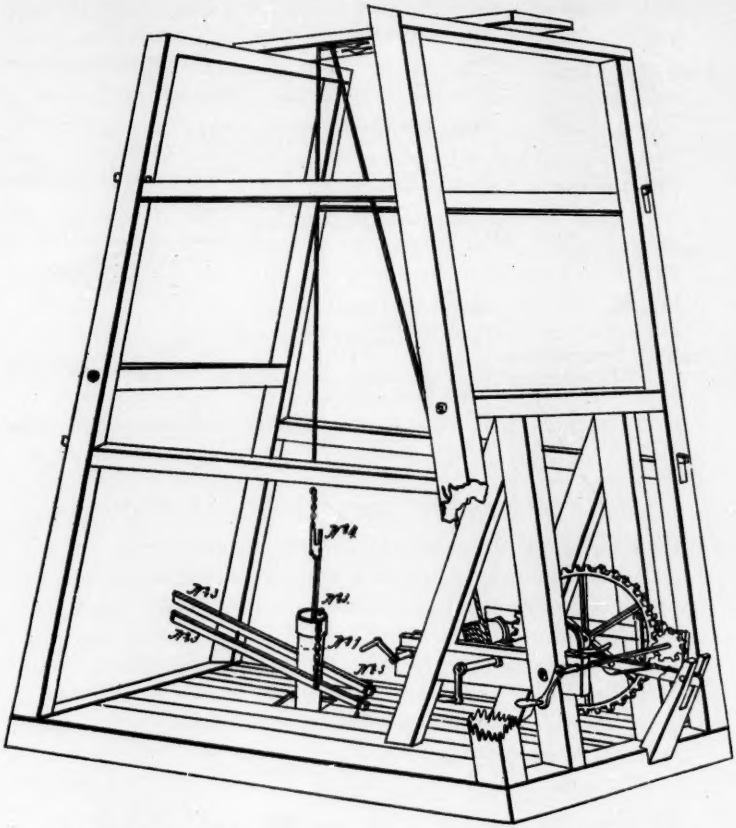

FIG. 2. Levi Disbrow's patent of Nov. 1, 1830. The drilling rig.

in 1830. By this time Disbrow had begun to use casing in his wells which was forced down by means of levers while the hole was being drilled. Figure 3 shows the improved array of tools used by Disbrow. An auger is shown as no. 2. A drill equipped

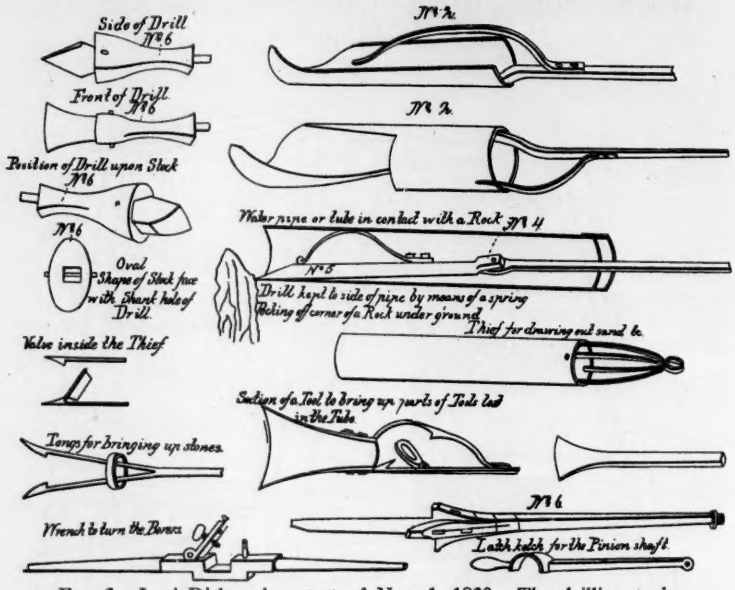
Side of Drill
Front of Drill
Position of Drill upon Stock
Oval Shape of Stock fits with Shank hole of Drill.
Valve inside the Thief
Tongs for bringing up stones.
Wrench to turn the Borers
Water pipe or tube in contact with a Rock
Drill kept to side of pipe by means of a spring
Thief for clearing out sand &c.
Section of a Tool to bring up parts of Tools lost in the Tube
Lath block for the Pinion shaft

FIG. 3. Levi Disbrow's patent of Nov. 1, 1830. The drilling tools.

with a spring for the purpose of holding the drill to one side of the casing while chipping at hard rock layers is shown as no. 4. Next to the spring-equipped drill is shown a sand bailer which we learn was called a "thief." A fishing tool had been devised as is shown next to the bailer. Tongs for catching and holding loose cobbles and rock fragments are shown beside the fishing tool. New types of drill bits are labeled no. 6 in the sketch.

CHARLESTON, SOUTH CAROLINA
1820–1880.

The first settlers of Charleston, South Carolina, had no difficulty in obtaining water. Sinking of dug wells disclosed be-

neath the surface 18 to 20 feet of quartzose sand which was saturated with water in its lower part. Underlying the sand was a thick layer of impervious blue-black clay. Consequently all the wells were sunk down to the clay, but no farther. From 1678 to 1820 dug wells not exceeding about 20 feet in depth were the chief sources of ground water for the residents of the city. With an increase in population and primitive disposal of sewage the shallow ground water became more and more polluted. Soon the more prosperous citizens of the town began to construct cisterns, mostly underground, in which rain water was stored.[10]

About 1820 a resident of Charleston named Longstreet made an attempt to obtain water from beneath the black clay which underlies the shallow water sands of the city. He dug a circular well 20 feet to the black clay and then sank an iron pipe through the clay to a depth of 57 feet. The water in the sands beneath the clay was under artesian pressure because of being confined by the clay bed. As a result the water rose in the well to within six feet of the surface.[11] This was apparently the first tubular artesian well in the United States to be constructed for the purpose of obtaining potable water.

It was not until 1876 that cable-tool drilling methods which had been in use throughout the states north of the Potomac since about 1825 were introduced in Charleston. The delay in their importation to Charleston may have been due, at least in part, to poor communication between the North and the South in the early part of the nineteenth century. In addition, the unindurated marl, clay and sand with only an occasional hard sandstone or limestone layer which underlies Charleston did not especially call for cable tool equipment, which was developed for use on indurated rock strata.

In 1823 the city of Charleston undertook to drill a well in the yard of the city Poorhouse on Mazyck Street. A resident of Charleston had sent home from London detailed descriptions and drawings of the tools used in boring a well in London. Using

[10] Lynch, P. H., Shepard, C. U., Jr., Geddings, J. F. M.: Artesian wells. Municipal Report of the City of Charleston, S. C., Charleston, S. C., 1881. Pp. 4, 5.

[11] *Ibid.*, p. 5.

tools based on these specifications and workers and superintendants of no previous experience in well boring, the boring crew finally penetrated the sands and clays beneath the city to a depth of 335 feet. It took the boring crew six months to bore six feet through a very fluid quicksand. At 335 feet a cap screw of the iron auger-rods failed and the rods fell to the bottom of the hole, forcing abandonment of the well.[12]

Some idea of the technique used in boring this well may be obtained from a description of the boring of a well in the garden of the Horticultural Society at Chiswick, near London, which may have been the same well studied by the resident of Charleston.

> The tackle and the instruments used were very simple. A scaffolding was raised 20 feet above the proposed orifice of the well, on which a platform was fixed to support a windlass, by which the rods used in boring were lowered into, and raised from the well. These rods were of tough iron, about an inch and a half square, and ten feet long, the ends of each screwing on to, or unscrewing from, the top of the next, as they were lowered into, or raised from the hole. The instruments—fixed, as occasion required, to the lowest extremity of the series of rods, when in action—were augers of various dimensions, for boring: steel chisels, for punching: and a hollow iron cylinder—called a shell—fitted with a valve at its lower end, for bringing up soft mud. The rods, when an auger was attached to them, were turned round by means of movable arms or dogs, which were made to lay hold of the part of the uppermost rod, at the top of the hole: the auger, being thus forced through the stratum of clay or sand, was drawn up, as soon as its cavity was filled with the substance it had loosened. The chisels were employed for punching through stones, hard chalk, or other hard substances; the rods, when these were attached, were moved by means of a powerful beam, acting as a lever, and worked by four men.[13]

The use of steel chisels for cutting through strata of hard rock suggests an independent development of at least some features of the standard rig in England.

[12] *Ibid.*, pp. 6, 7.

[13] [Disbrow, Levi]: An essay on the art of boring the earth for the obtainment of a spontaneous flow of water with hints toward forming a new theory for the rise of waters. Rutgers Press, 1826. P. 15. (Probably quoted from The American Farmer.)

In 1825 a second unsuccessful attempt was made to bore a deep well in Charleston. A third attempt was successful, a flowing well being completed at a depth of 109 feet.[14]

In 1844 Major Bowman, the engineer in charge of construction at Fort Sumter, in Charleston Harbor, began the work of boring a well to supply the garrison with water. He used cast iron casing, iron boring rods an inch and a half in diameter, boring augers, chisels, sand bailers, and other tools based on English boring methods. At 347 feet a connection on the iron rods broke and the tools were lost, causing abandonment of the well.[15]

In 1845 the city council of Charleston ordered a new attempt to complete a well for the city. The tools and methods employed on this well were based on the London methods of using augers, chisels, sand bailers and cast iron drilling rods. A few months after the Fort Sumter well met disaster the Charleston borers lost their tools at a depth of 290 feet.[16]

In 1846 the city council imported a well borer, A. C. Welton, who had bored many wells in Alabama. Using somewhat different tools from his predecessors at Charleston, he finally completed a three-inch well at a depth of 1260 feet. The water in this well rose in the pipes to 24 feet and 10 inches above the land surface, but flowed only 30 gallons a minute. Welton was then authorized to bore a six-inch well in an attempt to obtain more water. At a depth of 1230 feet, a sand bailer and part of the drilling rods were lost down the hole, and before they could be fished out the Civil War caused abandonment of the well in 1862. In 1867 Welton recommenced work on boring a well, but because of his advanced age he finally gave up the attempt.[17] In 1876 the city council hired Mr. F. Spangler, a well borer of considerable experience who used methods worked out in the West Virginia-Pennsylvania region. The report of the Scientific Committee of the City of Charleston tells us that he did not use a hand auger. It states: "For water-bearing or running sands, he, like

[14] Lynch, Shepard, and Geddings: op. cit., p. 7.
[15] *Ibid.*, p. 10.
[16] *Ibid.*, p. 10.
[17] *Ibid.*, pp. 10–12.

Mr. Welton, kept a steady pressure on his tubes, and used his bucket. He resisted the irruption of sand by the column of water on his tube. . . . For marls, clays, and hard rocks, he relied on his heavy chisel, weighing with its iron rod fully 1,000 pounds." [18] The description suggests use of a standard drilling rig, with percussion bits being used on all strata except loose sand, where a bailer was employed. The well was finished at a depth of 1970 feet.[19] The well flowed 250 gallons of water a minute and it is reported that the water could rise to a height of 103 feet above the land surface due to its artesian head.[20]

ALABAMA
1821–1900.

Some time between 1821 and 1833 the technique of boring wells was introduced in Alabama. The surface formations of Alabama are of three types. In the northeast part of the state igneous and metamorphic rocks outcrop. In this region surface drainage is well established and shallow dug wells would provide enough water for the limited demands in the early part of the 19th century. In the northwest part of the state occur Paleozoic sandstone, shale, limestone, dolomite, and chert. There are many springs in this area, surface drainage is generally plentiful, and shallow dug wells would have provided abundant water for the early settlers. In the southern half of the state occur the sand, clay, marl, limestone, and chalk of the Coastal Plain. In every part of this area except the Black Belt, surface drainage, springs, and dug wells must have provided the early settlers with all the water that they required. The Black Belt is a section of the Coastal Plain characterized by a black soil cover derived from the Selma chalk, which underlies the section. Drainage is intermittent in the Black Belt, for the chalk is impervious to water and

[18] *Ibid.*, p. 15.

[19] This well was apparently one of the three deepest water wells of the time in the United States. In 1858 a 2,086-foot well was put down at Louisville, Kentucky. In 1868 a well 3,147 feet deep was completed at St. Louis, Missouri. All three of these wells were put down by the standard drilling rig.

[20] *Ibid.*, p. 16.

there is no natural storage during the wet season to furnish water for the streams during the dry season of late summer and fall. Dug wells could supply little or no water due to the impermeable nature of the chalk. Since deep bored wells would have been most critically needed in the Black Belt, it is probable that the first wells were bored there.

In 1821 Dr. J. W. Huestis of Cahaba, Alabama, wrote a letter to the Hon. Samuel L. Mitchell, of New York, in which he discussed the problem of obtaining water in the prairie lands of the Black Belt around Cahaba. He stated that wells had been sunk in Cahaba to a depth of 60 or 70 feet, and that a few miles outside Cahaba a well had been sunk to a depth of 105 feet without finding water.[21]

In 1833 W. W. McGuire wrote a letter to the editor of *The American Journal of Science and Arts.* In this letter, which was titled "On the Prairies of Alabama," McGuire discussed the "rotten limestone," now known as the Selma chalk. He stated:

> This rock has been penetrated by boring to depths varying from one hundred to five hundred and fifty feet; . . . On perforating [through] the rock, a full supply of good water, is always obtained, which uniformly flows over the top.[22]

The early tubular wells of Alabama were constructed by hand labor with the use of augers. An excellent description of the methods used in boring wells before the Civil War has been given by B. L. C. Wailes, first State Geologist of Mississippi. He stated:

> The process of boring, as I witnessed it in Lowndes County, is easy; the apparatus is simple, and attended with but moderate expense or consumption of time. . . . A tripod, formed of common poles, about thirty feet high, sustains a block over the aperature from which the boring rods are suspended, and which are managed by two laborers, who walk around at opposite ends of a short movable lever, connected with the iron bar, or *sinker,* which forms the upper section of the rods, and is provided with a series of holes, at suitable distances along its entire length, about ten feet,

[21] Huestis, J. L.: Cahawba Press and Alabama State Intelligencer, June 2, 1821.

[22] McGuire, W. W.: On the prairies of Alabama. American Journal of Science and Arts, 1st ser., 26: 94, 1834.

through which the lever is keyed, and by means of which it can be shifted and adjusted at a higher elevation, as the auger descends.

To the lower end of the sinker, wooden rods, in sections of about twenty feet in length, tipped with iron to admit of being screwed together as the work progresses, are attached; and these are elevated, as occasion requires, by the rope by which they are suspended, passing through the block, and connecting with a windlass, which may be worked, if necessary, by horse-power.

A bored log is usually inserted down to the indurated marl or lime-rock. This is necessary to prevent the loose incoherent earth or sand of the upper strata from caving in or being washed away. The log has an aperture sufficient to admit the free passage of the auger and rods, and is driven or forced down in one or more sections of twenty feet, suitably united, to the requisite depth, which is sometimes near a hundred feet.

When the compact rock is penetrated, and sandy, incoherent strata met with, tubing becomes necessary; sheet-iron is generally used for the purpose, but cast-iron pipes are considered more suitable.

Thirty feet a day can be bored in the soft lime rock, but not more than ten in the sand-rock or green-sand. Fifty feet is sometimes accomplished the first day.

The ordinary charge for boring is thirty-three cents per foot for the first three hundred feet; for the next two hundred feet, fifty cents; and over five hundred feet, one dollar per foot.[23]

Figure 4 reproduces an illustration from Wailes' book which shows the tripod, block, sinker, levers, and some of the implements used in boring the wells.

The report of the Scientific Committee appointed by the City Council of Charleston, S. C., gives a good description of A. C. Welton's method of boring wells. As stated earlier in this paper Welton was brought into Charleston from Alabama in 1846 to bore a well for the city. They state:

He used rods, not of iron, but of wood, armed at each end with iron screws, so that they could be connected firmly together. His auger and tools were of new and ingenious pattern, mostly his own inventions.

. . . . . .

For strata of hard rock Mr. Welton used a chisel attached to an iron bar, both together weighing 300 pounds, and attached to the ordinary line

[23] Wailes, B. L. C.: Report on the agriculture and geology of Mississippi. E. Barksdale, State Printer. 1854. Pp. 265, 266.

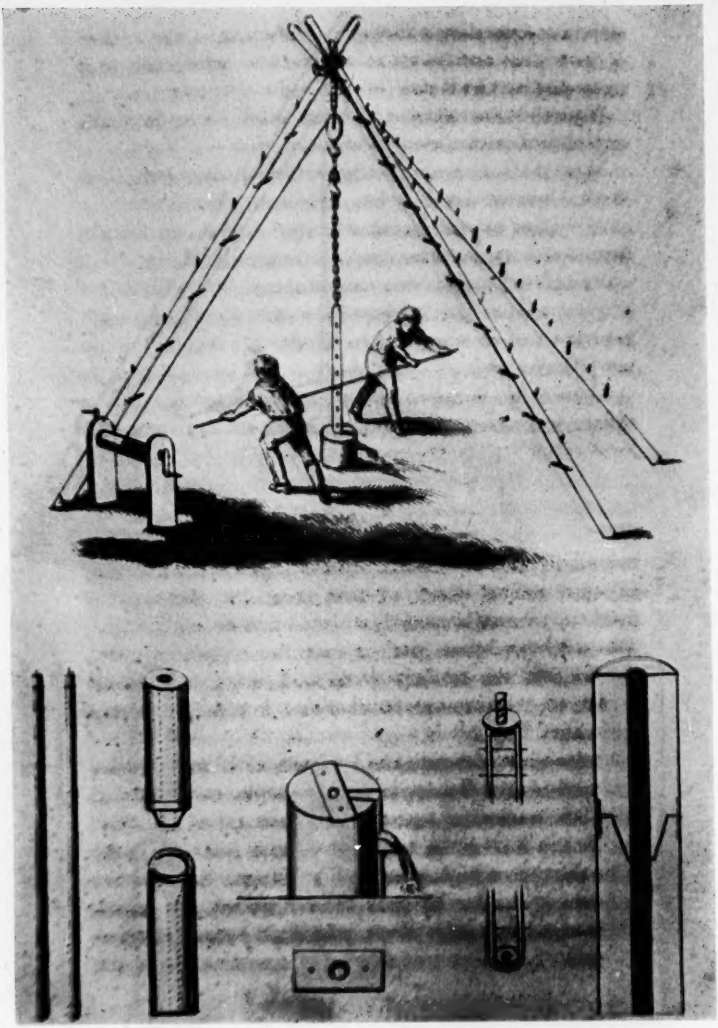

FIG. 4. Well boring in ante-bellum days in Mississippi and Alabama. (From Wailes.)

of rods by a slip line, which saved the many joints of the rods from the dangerous jar otherwise to be experienced at every blow of the chisel.[24]

The equipment used in boring wells in Alabama and Mississippi is almost identical with the equipment used in boring the well of the Horticultural Society at Chiswick, England, the only essential difference being the character of the rods. The well borers at Chiswick used iron rods, and the early well borers of the southern states used wooden rods with iron tips. Since well boring apparently did not begin in the deep south until after published accounts of the drilling of the well at London appeared in the United States, there is strong evidence that well boring was introduced into Alabama and Mississippi in much the same manner as its introduction in Charleston, S. C.—by direct copy of the methods used in England in the early 1820's. For example, on May 7, 1825, the *Cahawba* (Cahaba) *Press and Alabama State Intelligencer* published an account of the visit of Dr. S. McCulloh to the new gardens of the Horticultural Society at Chiswick, in which Dr. McCulloh remarked upon the extraordinary overflowing well at the gardens of the Society.[25] Such news items may well have caused interested Black Belt planters of the day to investigate methods by which they too could obtain flowing wells.

During ante-bellum days in Alabama artesian wells were first considered of little value unless they overflowed. As L. Harper, State Geologist for Mississippi, stated in 1857, ". . . bored wells whose water does not rise spontaneously above the surface are of little use; the water must be pumped up, or dipped with a tube provided with a valve, and as the whole is only a few inches wide, they yield very little water at a time." [26]

The early Alabama well borers devised means of obtaining higher yields from the non-flowing artesian wells. After the well was bored, a cistern three or more feet in diameter was dug immediately adjacent to the bored well. A lateral opening was then put through from the cistern to the artesian well below the static

[24] Lynch, Shepard, and Geddings: op. cit., pp. 11, 14.

[25] Cahawba Press and Alabama State Intelligencer, May 7, 1825.

[26] Harper, L.: Preliminary report on the geology and agriculture of the state of Mississippi. E. Barksdale, State Printer, 1857. P. 285.

level of the water in the well. The water which flowed into and filled the cistern to the static level of the artesian well was then available for large scale withdrawal. Buckets up to the size of a half barrel were operated on a windlass by slave or mule power. The artesian cistern wells were apparently first developed in the Montgomery County section of the Black Belt, where no flowing wells could be obtained in the chalk lands.

Boring wells with the hand auger was the common method of obtaining artesian wells in the Coastal Plain section of Alabama, and in the other southern states, until late in the nineteenth century. A jetting outfit for use in putting down wells in unconsolidated deposits was built in 1884 by W. C. Wells.[27] The relatively unconsolidated nature of the Coastal Plain section affords ideal conditions for the jetting process, which consists of loosening material and elevating it to the surface by water under pressure. The water is forced through pipes to the bottom of the hole and out of perforations in the bit. The cuttings are then washed out by the force of the water. By the end of the century jetting had become the chief method of sinking tubular wells of small diameter in the Atlantic and Gulf Coastal Plain.

MISSISSIPPI, GEORGIA, AND FLORIDA

1840–1895.

In 1854 B. L. C. Wailes, State Geologist of Mississippi, estimated that there were about one hundred artesian wells in Mississippi as compared to more than five hundred in Alabama.[28] This might indicate that well boring had been introduced later in Mississippi than in Alabama, but it may also be due to the fact that the Black Belt, where such wells were most needed, lies chiefly in Alabama.

The successful completion of the Charleston well that was begun in 1846 encouraged certain residents of southern Georgia to try boring artesian wells. Between 1840 and 1850 about six at-

[27] Bowman, Isaiah: Well-drilling methods. U. S. Geol. Surv. W. S. P. 257: 26, 1911.

[28] Wailes, B. L. C.: op. cit., pp. 262, 263.

tempts were made to obtain artesian water, with some of the wells being bored as deep as 700 feet. None of the wells was successful, and it was not until 1881 that Col. John P. Fort completed an artesian well on his plantation sixteen miles west of Albany. In 1885 Capt. D. G. Purse completed an artesian well near Laurel Grove Cemetery, in the southwestern part of the city of Savannah. The success of these two wells encouraged other attempts at well boring, and the number of artesian wells in southern Georgia rapidly increased.[29]

The first successful artesian well in Florida which would overflow at the surface was drilled at St. Augustine about 1880 to 1882. The well is reported to have been put down by an experienced driller from the Pennsylvania oil fields.[30]

UNIVERSITY, ALABAMA,
December 10, 1942.

[29] McCallie, S. W.: A preliminary report on the artesian-well system of Georgia. Georgia Geol. Surv. Bull. 7: 63, 64, 1898.

[30] Letter in possession of the writer from V. T. Stringfield, U. S. Geol. Surv.

SUPERGENE MAGNETITE.

JOHN S. BROWN.

ABSTRACT.

Available evidence regarding occurrences of magnetite believed to be of supergene origin is assembled, and the conclusion drawn that they are reasonably common, although economically unimportant. Field occurrences and laboratory data suggest that such magnetite is formed only below the water table, or in a water basin, where a delicate and usually unstable balance between oxidizing and reducing tendencies exists and a suitable precipitant, such as calcium carbonate or a hydroxide, is present. The resulting magnetite generally is very fine-grained, and usually is associated with much larger amounts of soft earthy hematite, and minor quantities of minute specularite grains. Ringed alternations of magnetite and hematite, as in oolites or centripetal replacements, are very common.

INTRODUCTION.

VARIOUS articles in Economic Geology for several years past imply the continuation of a long-standing uncertainty as to whether or not magnetite can form in appreciable quantity, if at all, from cold, dilute solutions. Recently Schwartz and Ronbeck [1] summarized an extensive study of magnetite occurrences in sulphide ores with the statement that "magnetite with sulphides occurs in deposits generally classified as of magmatic, pyrometasomatic, or hydrothermal origin. It is practically absent in other types of deposits."

As a broad statement this doubtless is true, but its too rigid acceptance easily led the authors into a misreading of some of their basic data as pointed out by myself in a discussion of that article.[2] Spiroff previously presented the affirmative view regarding low-temperature magnetite and Gruner [3] took issue with his

[1] Schwartz, G. M., and Ronbeck, A. C.: Magnetite in sulphide ores. ECON. GEOL. XXXV: 585–605, 1940.

[2] Brown, J. S.: ECON. GEOL. XXXVI: 100, 1941.

[3] Spiroff, K.: Magnetite crystals from meteoric solutions. ECON. GEOL. XXXIII: 818–828, 1938.

Gruner, J. W.: Discussion. ECON. GEOL. XXXIV: 342–343, 1939.

conclusions, at least in this instance. Without taking sides as to the specific illustrations cited in this debate, the writer wishes to point out that the affirmative also had been stated previously in recent years with some substantiating citations,[4] to which further evidence now can be added.

MAGNETITE IN THE BEDDED IRON ORES OF EUROPE.

Of the instances mentioned in the article just cited two are particularly interesting since they represent quantities of magnetite of geological significance even if not of much commercial importance. Cayeux [5] describes a lenticle of magnetite-bearing oolite of considerable extent in the district of Pienne, and several irregular areas in the district of Hayange, in the Lias beds of the sedimentary iron formations of Lorraine. The magnetite occurs in close association with hematite and chlorite, under conditions which seem to imply clearly that it is merely one phase of the process by which these sedimentary iron ores were formed.

Some magnetite is present as interstitial cement, but the bulk of it occurs in the oolites themselves. The following modes of occurrence are listed.

1. Oolites of massive uniform magnetite, the most widespread occurrence.
2. The outer envelope only composed of magnetite, the inner portion of chlorite and hematite in variable proportions.
3. In irregular shapes extending from one oolite to another.
4, 5, 6. Various combinations and gradations.
7. In broken oolites, some of which were fractured before and some after the deposition of magnetite.

These relations are very similar to those under which the predominant hematite of the ores was formed.

[4] Brown, J. S.: Supergene sphalerite, galena and willemite at Balmat, N. Y. ECON. GEOL. XXXI: 331–354, 1936. See p. 343, 351, Fig. 1.

[5] Cayeux, L.: Les Minerals de Fer Oolithique, Vol. 11, 306–321, 349–381, 384–392. Fig. 17. Paris, 1922.

Magnetite, like hematite, is found replacing fossils. Cayeux says (p. 310),

> The mineralization of the remains of mollusks furnishes material for interesting observations. The fragments of mollusks, converted into subcylindrical little batons, can be found in all stages of chloritization and hematization, and some chlorite-hematized. One curious kind is hematized on one side and chloritized on the other, the two parts separated by a sharp line. Others are entirely replaced by solid magnetite. Nearby are pieces composed of calcite and magnetite, or of calcite, chlorite and magnetite, or again of chlorite and magnetite. In these various combinations, the magnetite seems always to have replaced carbonate of lime.

In Britain, Hallimond[6] (p. 25) states that magnetite "is present exceptionally in the Welsh ironstones and in the Inferior Oolite ore at Rosedale in Yorkshire, and at Easton Neston in Northants. The Welsh ores have undergone a certain amount of recrystallization, but the last two ironstones are unaltered, and it seems clear that magnetite is a primary constituent."

Again (pp. 75–76) he mentions oolites at Rosedale which "show well-marked outer zones of finely divided magnetite, which sometimes also forms inner zones," and at Easton Neston finds "oolites zoned with magnetite."

Since the bedded iron ores in these regions consist predominantly of oolitic hematite and their sedimentary origin is not seriously questioned, it seems certain that the minor amounts of associated magnetite must have formed under peculiar local conditions at about the same time and in essentially cold solutions.

A further account of similar occurrences in the Soviet Union appeared in 1940.[7] Because of much better detail with respect to important aspects of identification and genesis it seems worth quoting at considerable length.

> The deposits of iron ores in the region of Khalilovo, Chkalov district, belong to the sedimentary diagenetically altered deposits and have been

[6] Hallimond, A. F.: Mem. Geol. Surv. Great Britain, Spec. Rep., XXIX: 25–26, 75–76, 1925.

[7] Krotov, P. B.: On the occurrence in the Khalilovo iron deposits (Urals, Russia) of magnetite formed from solutions of superficial origin at low temperatures. Competes Rendus (Doklady) des l'Academie des Sciences de l'U.R.S.S. XXVI: 801–803, 1940. In English.

formed in water basins of Jurassic age within the Baimak depression at these places, where it lies within the area of development of serpentinites.

The ore deposits in their major part are composed of hydrogoethite-chlorite ores of various structure; at the base of the deposits usually lie stratified ores which farther upward pass into pisolitic-oolitic ores; the latter are gradually substituted with clayey conglomerate-like pisolitic-oolitic ores. . . .

The strata containing the ores are described as clayey to sandy with some carbonate and occasional fossil plant remains, and with some interstitial magnetite probably of clastic nature.

But besides magnetite of clastic nature within the pisolitic-oolitic ores there occurs some magnetite of a different origin present in three forms of segregation: as pisiform grains in the composition of pisolitic-oolitic ores, as a continuous crust with regular crystals in the cavities at the surface of serpentinites, and as veinlets cutting bedded and pisolitic-oolitic ores.

Pisiform grains composed of magnetite were found in the Novokievsky, Malo-Khalilovsky, Orlovsky and Novopetropavlovsky deposits, and had been previously reported by the author.

Some of them have the appearance of compact segregations of a rounded shape which are sometimes broken by fractures of dessication; others present fragments of plants with a preserved cellular structure. In some cases the plants are replaced by magnetite only at the periphery, and in others fully. Similar structures have been described by Cayeux under the name of pseudo-oolites or false oolites from the oolitic ores of Lorraine. (See previous page for reference.) In section A of the Malo-Khalilovsky deposit in the pisolitic-oolitic ores the pisiform grains of magnetite containing inclusions of chromite are accompanied with small concretions of marcasite.

The nature of the pisolitic structures shows that they have been formed by way of a chemical precipitation of iron oxide from solutions, a part of the ferric oxide being reduced to ferrous oxide owing to the presence of decaying vegetable remains. The precipitation of the oxides occurred on decaying plants or around sand particles on the bottom of the basin.

The second form of segregation of magnetite—a solid crust—was observed on the surface of carbonated serpentinites, underlying the Orlovsky deposit. The serpentinites have an uneven surface, with crests and hollows. Some of the crests have been replaced by a solid mass of magnetite to a depth of 10–15 cm. The cavities in serpentinites are covered with overgrowths of magnetite octahedra of a thick tabulated shape. The analysis of the magnetite from the Orlovsky deposit is as follows: Fe_2O_3–71.55; FeO–23.35; SiO_2–1.62; TiO_2–0.08; Al_2O_3–0.74; H_2O + 1.29; H_2O–

0.08; Σ 98171. Analyst: A. Petroyson, Lomonosov Institute of the Acad. of Sciences, 1936.

In other parts of the same deposit the crust on the serpentinites consists of solid marcasite, which has passed directly into hydrohematite or hydrogoethite.

Finally, magnetite has been found as crystals overgrowing the surfaces of cracks and cavities in ochred coarsely-bedded ores in the Malo-Khalilovsky deposit. Here the magnetite forms regular crystals, bounded by (111) and (110) faces. The magnetite is sometimes covered with isolated rhombohedra and brushes of siderite, converted at a later date to hydrogoethite. The analysis of the magnetite is as follows: Fe_2O_3–67.27; FeO–30.17; SiO_2–0.91; TiO_2–0.0; Al_2O_3–0.0; MnO–0.05; CaO–0.28; MgO–0.36; NiO–0.06; H_2O + 0.53; P_2O_5–0.89; Σ 100.49. Analyst: Niessenbaum, Inst. of Geological Sciences of the Acad. of Sciences, 1939.

Moreover, in the same deposit there are veinlets of a massive magnetite, now gradually dying out in the ore, and then ending in dilations of the shape of a small nodule. The boundaries of the magnetite veinlets with respect to the wall rock—the bedded ore—are uneven, of the nature of replacement, the magnetite in the marginal parts containing inclusions of the wall rock.

In the Novokievsky deposit the magnetite forms cutting veinlets of a granular structure, up to 4 mm. thick.

Siderite in small rhombohedra occurs not only on magnetite crystals, but also in small cavities throughout the ore layer. The formation of the siderite belongs to a later age than that of the magnetite, namely, to the epoch of lowering of the level of ground waters subsequent to the formation of siderite nodules in the upper portions of the ore deposit. The formation of siderite took place at the end of the Mesozoic, or, most probably, in the Cenozoic, when the deposit was exposed at the surface and was subject to weathering processes.

The formation of the magnetite veinlets occurred at an earlier age and, judging by the presence of magnetite in the composition of the pisolitic-oolitic ores themselves, its origin seems to refer to the epoch of diagenesis of the sediments in the basin and their chloritization. At that time the waters impregnating the sediments, that contained iron oxides, precipitated them as magnetite, since a part of the ferric oxide segregated was reduced by decaying organic matter or hydrocarbons. The mode of occurrence of magnetite in fissures in the ores of the Khalilovo deposit gives no ground to refer it to minerals of hydrothermal origin, since the fissures it is found in occur only within the ore deposit, and the formation of the magnetite refers to a time when no volcanic phenomena were displayed in the Urals. . . .

MAGNETITE IN SUPERFICIAL OXIDATION ZONES.

There are a number of recorded instances of magnetite in shallow oxidation zones, most of them, unfortunately, not fully substantiated by positive identification of the magnetic material. Thus Cummings and Miller mention magnetite as an accessory mineral in the lateritic iron ores of Cuba,[8] associated with abundant hematite and considerable limonite. The identification of magnetite, however, seems to lack confirmation by positive analytical or mineralogical data, although it is accepted by Lindgren in the last edition of Mineral Deposits (4th Edit., 1933, pp. 360–361).

Similarly Frasche[9] recently included magnetite among the accessory oxidation products in lateritic iron ores of the Philippines, but again without positive evidence of proper identification.

Several other references to minor occurrences of magnetite in oxidation zones have been noted but are so brief and vague that they are hardly worth citing.

GOSSAN NEAR LONG LAKE, ONTARIO.

A minor example of magnetite believed to be of supergene origin was noted by the writer in Olden township, Frontenac County, Ontario, about 40 miles north of Kingston in the southern part of Concession 111. In a narrow belt of Grenville limestone trending nearly east-west, several unimportant zinc prospects occur. They consist of dark sphalerite usually mildly oxidized along the outcrop, with resultant impregnation of the adjacent limestone by limonite and hematite. At one locality no sphalerite is visible but only a weak gossan with a considerable scattering of hematite, mainly in cracks and fractures in the limestone. In many cases the cracks contain a narrow central seam of dark magnetic iron oxide. Thin and polished sections indicate that the

[8] Cummings, W. L., and Miller, B. L.: Characteristics and origin of the brown iron ores of Camaguey and Moa, Cuba. A.I.M.E., Trans. 1912. See esp. p. 134. See also Leith, C. K., and Mead, W. J.: Origin of the iron ores of central and northeastern Cuba. Idem, pp. 90–102.

[9] Frasche, Dean F.: Origin of Surigao iron ores. Econ. Geol. XXXVI: 280–305, 1941.

material is magnetite, which formed mainly as a fracture filling, but also to some degree as a dissemination through the limestone. Subsequent to the formation of magnetite the fractures were reopened and veined by calcite and this secondary calcite and the adjacent limestone were then mildly stained by earthy hematite. Fig. 1 *A* is a photomicrograph of this magnetite.[10]

There is no accompaniment of high temperature minerals or alteration and the gossan-like showing is evidently superficial. The magnetite is interpreted as simply an early stage in the process of oxidation around a minor sulphide showing and the hematite as a later stage, the latter perhaps at shallower depth due to erosion.

BALMAT ZINC MINE, NEW YORK.

The Balmat occurrence[11] is of sufficient magnitude to have geological significance, for although the quantity of magnetite is subordinate to that of earthy hematite and secondary sulphides, it, nevertheless, amounts to some thousands of tons. As stated in the original description, magnetite occurs only well down in the oxidized zone, or more properly in the zone of secondary enrichment, and was deposited chiefly, if not entirely, below the water table. It is restricted to the body of the altered sulphide mass, and usually to the actual limits of oxidized pyrite grains, which are replaced concentrically inwards and along fractures, by a mixture of magnetite with earthy hematite, accompanied by a little specularite, much secondary sphalerite and some secondary galena. A typical illustration of these relations is shown in Fig. 1, *B*. Although this magnetite is very fine-grained, it is possible at high magnification in polished sections to identify many minute octahedral crystals.

ARTIFICIAL MAGNETITE.

Spiroff[12] describes laboratory experiments in the production of magnetic ferruginous precipitates, attaching considerable im-

[10] I am indebted to Eugene N. Cameron of Columbia University for the photomicrographs in Fig. 1 and for assistance in the identification of the Long Lake magnetite.

[11] Brown, J. S. *Op cit.*

[12] *Op. cit.*

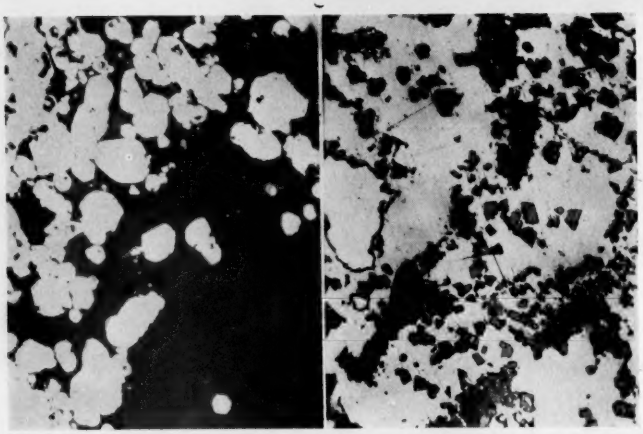

FIG. 1. *A* (Left). Secondary (supergene) magnetite crystals in fractured Grenville limestone from Long Lake, Ontario. Dark areas, limestone and secondary calcite stained with limonite. ×130. *B* (Right). Supergene magnetite crystals (dark gray), from Balmat, N. Y. Bright white, remnant of large primary pyrite grain. Dark gray, ragged areas are supergene sphalerite discolored by earthy hematite. Dull white, supergene galena. The interpretation is that original primary pyrite and sphalerite were replaced, first, by supergene sphalerite, with contemporary formation of hematite and fine-grained magnetite. The supergene hematite-sphalerite were then replaced locally by supergene galena which did not attack the magnetite crystals. Magnetite crystals are most abundant in the secondary sphalerite but the secondary galena gives the best photographic background. ×165.

portance to them, and proposes several equations in explanation. Gruner [13] says:

Spiroff devotes half his article to the well-known chemical reactions of iron compounds to prove his point that a black magnetic precipitate of iron oxide can be formed in the laboratory at room temperatures. It is known that such precipitates on drying oxidize with extremely great ease, resulting in a dark brown magnetic Y Fe_2O_3 which cannot be distinguished from Fe_3O_4 in x-ray diffraction powder diagrams.

[13] *Op. cit.*

It occurred to me that it might be significant to inquire into the manufacture of certain fairly common pigments known as black oxide of iron or black magnetic rouge, and sold under various trade names, one being Mapico from the Magnetic Pigment Company of Trenton, N. J., which markets some hundreds of tons annually for use in printing inks, as polishing powder, etc. I find that this material, which is a very black and highly magnetic powder, has been produced for over thirty years under patents granted to Peter Fireman (No. 802, 928–1905: No. 857, 044–1907). The second patent describes only minor improvements in the first. The original patent is very prolix, so that only portions are quoted.

I start out with a ferrous salt which I first dissolve in water to make up a rather dilute solution. The waste ferrous liquors obtained by pickling sheet-iron, &c., would be quite suitable. The solution contained in a tank is then at once completely precipitated in the cold by carbonate of soda added in slight excess. The precipitation can also, if preferred, be made with caustic soda or some other soluble hydroxid or carbonate. Immediately after the addition of the precipitating agent has begun heat is applied and a rapid current of air is introduced, which stirs up the liquid and the precipitate most energetically. . . . The operation is terminated by bringing the liquid, after the air has been shut off, to boiling and maintaining it for a few minutes at that temperature. . . .

There follows an extended discussion of the difficulty of knowing just when to stop introducing air, and of an analytical procedure to determine this point.

It was soon found out that no matter at what stage of oxidation the blowing in of air had been stopped the product continued to undergo oxidation to a very great extent during the subsequent filtering, washing, and drying—chiefly during the drying—even if carried out at temperatures not exceeding 60 centigrade. This explained how a product of a fine black color immediately after the oxidation in the precipitation-tank became reddish-brown on drying. The oxidation by the current of air in the tank had been allowed to proceed too far. On the other hand, it was found that there was such a thing in my process as insufficient oxidation. If the oxidation by the current of air had been stopped too soon, the product turned rusty-brown during the washing and more so during the drying, the oxidation in this case tending to the formation of a ferric rather than

of a ferro-ferric compound. The analytical method also explained how a product of not such a good black color in the precipitation-tank could yield a good pigment in the end. . . . The best mode of drying proved to be the following: The washed and pressed precipitate is placed within a closed iron cylinder provided with a tube, to which a valve is attached to allow the water-vapor to escape, but to prevent the air from coming in. This cylinder is inclosed in a wider one. The heating takes place by means of steam passing between the two cylinders. Making use of superheated steam, a temperature of 150 centrigrade or more is conviently maintained. Under these conditions the pigment dries expeditiously and practically without oxidation. In this way a beautiful black pigment is easily obtained with a composition not deviating much from that of the mineral magnetic oxide, and to accomplish this result the product in the precipitation-tank is allowed to become oxidized by the current of air until the ratio of ferrous to ferric iron nearly reaches that of one to two. . . .

Strangely, I find no mention of this process in several standard texts of mineralogy or in "Data of Geochemistry." Mellor,[14] however, discusses the aqueous methods of producing magnetic iron oxide in considerable detail, giving many citations, including the Peter Fireman patent and also a German patent. The following excerpts seem worthy of quotation.

R. Phillips found that if a mixture of ferrous sulphate and sodium carbonate be treated with sufficient potassium chlorate added all at once, hydrated ferric oxide is formed, but if added in small portions at a time, the black ferrosic oxide is formed, and is not affected by subsequent addition of the chlorate. W. Gregory found that when a solution of ferrous sulphate is divided into two equal parts, and one part is oxidized and mixed with the other, and both precipitated from the boiling solution by ammonia, a black, highly magnetic oxide is formed—vide infra, hydrated ferrosic oxide. J. Altfield described a similar process. In C. F. Wulfing's process, as described by F. J. R. Carulla, some ammonia is added to a ferrous liquor-say waste liquor used for pickling iron- and air is blown into the mixture to oxidize the lower oxide. More ammonia is added to decompose completely the ferrous salt in solution, and the combination of the two oxides is brought about by heat and steam, or air press. The product is used as a magnetic oxide paint for protecting iron from corrosion.

[14] Mellor, J. W.: A Comprehensive Treatise on Inorganic and Theoretical Chemistry. Vol. XIII, Pt. 2, pp. 731–774 (see p. 739), 1927.

The common practice of applying moderate heat, up to the boiling point, in these commercial processes may be offered as an objection to their bearing on natural occurrences. It seems likely, however, that this is mainly to promote speed and efficiency, since magnetic material evidently can be produced in the cold, although more slowly, and with the usual result of brownish, oxidized admixtures when free air is present. In nature it is fairly certain that free air is excluded in the zones, below the water-table, or a water surface, where magnetite is likely to be formed, and there may be even sufficient hydrostatic pressure to have some effect in the process.

CONCLUSIONS.

The field and laboratory evidence set forth seems to me to lead unequivocally to two conclusions.

1. Magnetite has formed at a number of localities by natural supergene or superficial low-temperature processes, but, as far as present knowledge goes, only in small amounts, and in most cases subsidiary to larger quantities of hematite. The associated hematite is chiefly of the red earthy variety but may include a minor proportion of fine-grained specularite.

2. Magnetite forms in such situations only when a favorable, and rather delicate balance exists between oxidizing and reducing tendencies. Proper conditions probably always involve the presence of a ferrous salt, usually the sulphate or carbonate, and a precipitating agent, analogous to the ammonia so popular in laboratories, which in some cases may be calcium carbonate or a related basic compound. In sulphide masses, however, it seems likely that precipitation is more often affected directly by sulphides or their sulphur derivatives such as free sulphur or hydrogen sulphide.

Supergene or low temperature magnetite seems to be distinguished commonly by fineness of grain and frequently by its association with more obvious products of oxidation, particularly earthy hematite. Because the chemical balance required for its formation is easily upset, ringed alternations with hematite are

apt to be characteristic. Since the exclusion of free air or active oxidizing agents is essential, supergene magnetite is unlikely to form above the water level, and should be sought rather in the zone of secondary enrichment and precipitation. In sedimentation it would appear to form occasionally under water when a strongly oxidizing environment shifts temporarily toward a neutral or reducing state, and perhaps conversely when a predominantly reducing environment becomes mildly oxidizing. In the latter situation magnetite probably need not be associated with hematite, but no good illustrations have come to my attention.

BALMAT, NEW YORK,
Oct. 16, 1942.

DISCUSSION AND COMMUNICATIONS

SOME CONCEPTS ON THE GEOLOGY OF QUICK-SILVER DEPOSITS IN THE UNITED STATES.

Sir: The paper by Ross [1] represents the distillation of much experience and field work on the subject. Its value is enhanced by the fact that it deals with a mineral which seems to be the best possible springboard for an attack on the solution of the problem of the composition of mineralizing solutions.

In the case of almost any other mineral we are handicapped by the complexity of the depositing solutions, and environments involving pressures and temperatures beyond reproduction in the laboratory. Here, as Ross shows, is a mineral deposited "at geologically shallow depths, and at relatively low temperatures and pressures," and by "dilute hydrothermal solutions of relatively simple composition. . . ."

Since this is such an important mineral from this aspect it is necessary to scrutinize theories of origin with exceeding care. The alkaline sulphide theory formulated by Becker [2] from an original suggestion by Christy [3] seems to monopolize the field. It has been accepted without reservation by recent writers.

Mercury sulphide is so insoluble in any but alkaline sulphide solutions that the origin of this theory resulted more from a search for a solution that could carry cinnabar than from a study of hot springs depositing cinnabar. The initial difficulty of the insolubility has probably contributed to the lack of any critical re-examination of this theory.

At the time of the work done by Becker and Melville, the dissociation theory was so recent that it is doubtful if either man

[1] Econ Geol. 37: 439–465, 1942.
[2] U. S. Geol. Surv. Mon. 13, 1888.
[3] Am. Jour. Sci. 3rd Ser. 17: 453–63, 1879.

was able to utilize the knowledge. Many considerable advances have been made in chemistry since 1888.

Ross [4] inherits one error of Becker and Melville in assuming that a decrease of temperature would decrease the solubility of HgS in alkaline sulphides. This is normally the case with the majority of substances, but Na_2S (the salt generally discussed) is the salt of a strong base and weak acid, and hydrolyzes very readily. The reaction is $Na_2S + 2\ H_2O = 2\ NaOH + H_2S$. This hydrolysis diminishes the concentration of the $S^=$ ions in solution, and as $\frac{(HgS_2^=)}{(Hg^{++})(S^=)^2} = K_{HgS_2}$ any decrease of the $S^=$ ion diminishes the concentration of the $HgS_2^=$ ion and hence the solubility of HgS as the square. In the range experimentally examined by Knox [5] from 25° to 33° C, solubility increased with diminishing temperature as a net result of:

1. An increasing solubility of HgS,
2. A decrease of the complex constant ($K_{HgS_2^=}$), the complex being less stable at a higher temperature, and
3. An increasing hydrolysis which diminishes the concentration of the $S^=$ ions.

Precipitation of cinnabar cannot be caused by decreasing temperature alone.

The chief objection to the alkaline sulphide theory was understood by Becker. Na_2S is neutralized by even such weak acids as H_2S, forming NaHS. It was well established at the time that HgS was insoluble in NaHS at room temperature. The insolubility is the result of the absence of $S^=$ ion, all the sulphur being converted to HS^-. Since Becker found H_2S present in excess in the hot spring waters depositing cinnabar at Sulphur Bank and Steamboat Springs, it was necessary for him to find an explanation for this apparent anomaly. Becker and Melville found that HgS was soluble in NaHS solutions at elevated temperatures. Becker states that H_2S is evolved according to the following reaction $NaHS + H_2O = NaOH + H_2S$, the H_2S escaping and the second step taking place, $NaOH + NaHS = Na_2S + H_2O$. However

[4] Ross: op. cit., p. 465.

[5] Trans. Faraday Soc. 4: 48, 1908–9.

the experiment was carried out in contact with air, bearing O_2 and CO_2.

The work of Knox,[6] carried out with elaborate precautions, shows that the decrease in solubility of HgS in Na_2S on increased temperature is caused by the hydrolysis of Na_2S to NaHS and decrease of $S^{=}$ ion. If the reaction which Becker says takes place is correct, we would have NaHS hydrolyzing to Na_2S, the reverse of Knox' finding.

That Becker is probably in error is shown by W. P. Bloxam[7] who found that solutions of alkaline hydrosulphides were stable on boiling and did not evolve H_2S. This is in direct contradiction to Becker. Bloxam also found solutions of alkaline hydrosulphides exposed to air with CO_2 oxidized to polysulphides, and solutions exposed to pure O_2 gave thiosulphates. The explanation of the solubility of HgS in NaHS at elevated temperatures is probably caused by the formation of polysulphides. The experiment should be repeated out of contact with the air to check this supposition, but the present writer does not have the facilities for such work.

If the above is correct then mercury sulphide cannot be carried in solution along with H_2S as the complex salt $HgS_2^{=}$, although Becker reported H_2S present at Sulphur Bank and Steamboat Springs and claimed that Na_2S was present. Becker did not actually find Na_2S in the spring water, he merely recalculated the analysis of the water on the basis of what he thought was present.

At Sulphur Bank in particular Becker found large amounts of gas being evolved. On analysis this was found to be composed of:

Carbon dioxide	89.34%
Hydrogen sulphide	0.23%
Methane	7.94%
Nitrogen	2.49%
	100.00%

It is difficult to see how the spring water could have been anything but acid, if gas of this composition was being evolved.

[6] Idem.

[7] Jour. Chem. Soc. 77: 753, 1900.

Other considerations also contradict the hypothesis of alkaline sulphide solutions. On p. 454 Ross states that, "the one condition that seems common to all (deposits of quicksilver) is that the structure at the time of mineralization permitted ready passage of solutions that lacked power to make openings for themselves or to move appreciably through the pores of an unfractured rock." Does this mean that these highly alkaline solutions did not react with the wall rock, composed in most instances of silicates? Mercury deposits are almost universally shallow, near surface phenomena. Why did not these alkaline solutions react at depth with the wall rock, and give rise to mercury deposits at depth.

Alkalinity must be high in these solutions, since Knox found that in a .05 N solution of Na_2S the hydrolysis was about 98.7 per cent complete at room temperature. Since $Na_2S + H_2O = NaOH + NaHS$ then one mol of Na_2S would give one mol of NaOH at 100 per cent hydrolysis. Therefore in dilute solutions the amount of OH^- ion present must be substantially equal to the amount of Na_2S regarded as originally present. Yet Ross says, "there is little evidence in most of these deposits that the solutions attacked the wall rock extensively." Alkaline solutions so strongly react with silicates that this aspect alone suggests that the solutions were not alkaline or at least that the solubility of HgS did not depend on the formation of $HgS_2^=$.

The presence of cinnabar is often quoted as evidence of the alkaline nature of the solutions. Allen and Crenshaw [8] state, "The black amorphous sulphide is always the first product when mercuric salts are precipitated by alkali sulphides, but on digestion with the latter at 100° it gradually passes into cinnabar." Note that cinnabar is not precipitated directly. In this and in other chemical combinations which precipitate mercuric sulphide the first product is always the black variety.

In discussing metacinnabar the same writers say [9] "On heating alone or more rapidly with ammonium sulphide or dilute sulphuric acid the metacinnabar passes into cinnabar. This is true for both the natural and synthetic mineral."

[8] Am. Jour. Sci., 4th Ser., Vol. 34, 1912.
[9] Op. cit., p. 375.

Cinnabar, then, supposedly a criteria of alkaline solutions, could be obtained by precipitation of metacinnabar in acid or neutral solutions which would change to cinnabar by "heat alone" or by contact with dilute acid solutions. The work of other writers shows H_2S will effect the transformation.

Since metacinnabar is so readily altered to cinnabar it is difficult to see how the solutions which deposited the metacinnabar orebody at Mount Diablo, California, could be anything but near neutral with small amounts of H_2S.

We should not rest completely satisfied with the alkaline sulphide theory until doubts such as these have been resolved.

JAMES POLLOCK

TUCSON, ARIZONA,
Dec. 17, 1942.

REVIEWS *

Economic Mineral Deposits. By ALAN M. BATEMAN. Pp. xi + 898; Figs. 300. John Wiley and Sons, Inc., New York, 1942. Price, $6.50.

For many years prior to the appearance of the first edition of Lindgren's *Mineral Deposits* in 1913, American students of mineral deposits were dependent on foreign textbooks. The fourth edition of Lindgren was published in 1933. This work has been a very satisfactory comprehensive treatment of mineral deposits. Another satisfactory, somewhat less voluminous, textbook has been Emmons' *Principles of Economic Geology*, first published in 1918 with a second edition in 1940. These two works differ in the arrangement of the descriptions of mineral deposits. Lindgren described the deposits according to genetic groups. Emmons described them according to substances. Despite the broad scope of the titles, neither text included the mineral fuels. Lindgren referred to the custom of dividing mineral deposits into two groups—the metallic and the non-metallic—as a line of division "which can hardly be defended except on the ground of long-established habit," but made no apology for the omission of mineral fuels. Emmons explained the omission of the mineral fuels on the grounds that their adequate treatment would make his book "so voluminous as to defeat some of its purposes." Bateman's *Economic Mineral Deposits* more courageously pioneers in covering the entire field of mineral deposits—the metallic, the non-metallic, and the mineral fuels. The general plan of the book is more like that of Emmons in that a discussion of principles and processes is followed by a description of deposits according to substances. In comprehensiveness and magnitude, it is more like Lindgren's. All three authors are essentially metalliferous geologists, and all three works are more satisfactory treatises of ore deposits than they are of the non-metallic mineral deposits. Bateman, however, has treated more satisfactorily both the metallic deposits and the non-metallic deposits in a single volume than have the other two.

The first editions of both Lindgren and Emmons were written when the development of genetic classifications reached its culmination and both books are patterned accordingly. Since that time, other features of

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

mineral deposits have received greater attention and shortcomings of the genetic classifications based on temperature and pressure have been more clearly recognized. Bateman has departed from the conventional treatment of principles and processes established during the first two decades of the century and has emphasized the newer knowledge that has since accumulated. In this respect, *Economic Mineral Deposits* presents refreshing novelty. No economic geologist who possesses the energy required to compile an up-to-date comprehensive textbook on mineral deposits has had a wideness of experience that better qualifies him for the task than has Bateman. His wide practice as consulting geologist has enabled him to assemble a wealth of first hand information and to evaluate that information, his long service as editor of Economic Geology has afforded him unique opportunity to inspect critically the important contributions to the science, and his many years of teaching have given him practice in preparing the material in form that is interesting and comprehensible to students. Both in the contents of the volume and in the mode of presentation are ample evidence of this varied background. Another novel feature of the volume is its departure from the conventional formality of presentation that characterizes textbooks and the frequent indulgence in homely illustrations and figures of speech that impart an element of human interest to the style. He who views the book as a whole must recognize it as a needed addition and not as just another textbook in the field and will praise it as an excellent piece of work. He who disregards the forest, and focuses his attention on the trees, will not always be wholly in accord with the contents of the volume.

The volume comprises three parts. Part I, discussing principles and processes, occupies 48 per cent of the pages; Part II, describing metallic mineral deposits, embraces 24 per cent of the pages; and Part III, describing non-metallic mineral deposits, includes 28 per cent of the pages.

Part I dealing with principles and processes is naturally the most important part to the economic geologist. It is the part that gives the author the fullest opportunity to present his interpretation of the science and display his expertness in the science. It is the part in which he is free to choose the topics that his experience has proven comprise the essential features of the mode of occurrence and origin of mineral deposits and that properly correlate the geology of the deposits with the related arts and with the economics of the mineral industry. Six of the eleven chapters of Part I are devoted to the geology of mineral deposits, treating respectively Materials of Mineral Deposits and their Formation; Magmas, Rocks, and Mineral Deposits; Processes of Formation of Mineral Deposits; Controls of Mineral Localization; Folding and Faulting of Mineral Deposits; and Classifications of Mineral Deposits. They are followed by three chapters dealing respectively with Resources, International Re-

lations, and Conservation in Minerals; Geology in Prospecting, Exploration, Development, and Valuation of Mineral Deposits; and Extraction of Metals and Minerals. These three chapters deal with collateral information that the student is usually compelled to seek from other sources. The other two chapters are a brief introductory chapter defining the scope of economic geology and explaining the plan of the volume and a chapter devoted to a brief history of the use of minerals and the development of the science.

The chapter on Materials of Mineral Deposits and their Formation lists the common ore and gangue minerals and describes the chemical processes by which these minerals are formed and the physical conditions of their stability. It concludes with a two page table of geologic thermometers ranging from 1890° C. down to 70° C. The chapter on Magmas, Rocks, and Mineral Deposits reviews the theories of magmatic differentiation and discusses the separation of magmatic emanations and their physical and chemical character.

In the chapter on Controls of Mineral Localization are included discussions of zonal distribution and metallogenetic epochs and provinces. Only two pages are devoted to zonal distribution, and less importance is attached to its significance than has been attributed to it by numerous other writers. The early contributions of Spurr to this theory might have been amplified. Likewise, a discussion of the genetic significance of the parallelism of mineral zones and the paragentic sequence of minerals in ore deposits, including the work of Bandy, might have found place in this discussion. In the section on metallogenetic epochs, the silver-tin lodes of Bolivia are placed in an Early Tertiary rather than a Late Tertiary epoch. Objections to this correlation are presented in a review of Ahlfeld's *Die Bodenschätze Boliviens* (ECON. GEOL., 35, 1940, page 113). In the examples of metallogenetic provinces, it is not clear on what basis a copper province in Asia is considered "the extension from Germany of the Kupferschiefer." In explanation of metallogenetic provinces is ventured the speculation that metals may in magma depths undergo some unknown atomic change which may create one or other of the metallic elements. More objective and no less enlightening is the admission earlier in the same paragraph that the cause of metallogenetic provinces is unknown. The chapter on Folding and Faulting of Mineral Deposits is to be commended for the unusually large number of illustrations that supplement the text.

The longest and most important chapter of Part I is that on Processes of Formation of Mineral Deposits. It embraces 237 pages, or about 57 per cent of Part I. The processes discussed are magmatic concentration, sublimation, contact metamorphism, replacement, cavity filling, sedimentation, evaporation, mechanical concentration, residual concentration, oxi-

dation and supergene enrichment, and metamorphism. The section on magmatic concentration is an excellent summary of the able exposition of this process in the author's presidential address to the Society of Economic Geologists. Contact metamorphic deposits and pyrometasomatic deposits are defined as essentially the same. It seems more logical to consider pyrometasomatic deposits to embrace broadly high temperature replacement deposits in the formation of which the physical conditions are sufficiently intense to give rise to reaction silicates or skarn minerals, whereas contact metamorphic deposits are such deposits formed in the immediate vicinity of an intrusive contact. Though the term is not clearly so defined by Lindgren, he actually made such a distinction in that he describes two groups of deposits under pyrometasomatic deposits: (1) contact metamorphic deposits and (2) pyrometasomatic deposits not related to contacts. The latter include deposits such as Franklin Furnace which have the mineralogic earmarks of contact metamorphic deposits but not their geologic position. If such a distinction is made, the term pyrometasomatism fills a real gap in nomenclature; if the distinction is not made, its usefulness is restricted to that of a synonym for contact metamorphism. So limited alteration of the intrusive rock in contact metamorphism is described as not to take cognizance of the extensive endomorphism in deposits such as those at Firmeza and Daiquiri in Cuba and in the Mexican examples described by Spurr. Question might also be raised regarding the statement that "invaded igneous rocks are not known to contain contact-metamorphic deposits." If as correctly stated by Bateman "at high temperatures hardly any rock may escape replacement," why are there no contact metamorphic deposits in invaded igneous rocks? If one accepts Knopf and Anderson's interpretation of the geology of the Engels deposits in Plumas County, California, are they not an example of contact metamorphic deposits in invaded igneous rocks! The process of replacement is described clearly and comprehensively. However, is not the term "metasomatic replacement" a redundant terminology that should be avoided. Mineral pseudomorphs are so generally the result of metasomatism that it perhaps borders on quibbling to point out that they are not always so. It perhaps likewise borders on quibbling to question the statement that "disseminated replacement deposits are generally huge" since two pages further on is the statement that they "range in size from small to the dimensions of the Chuquicamata deposit." What is meant is that generally only the huge ones are mined. In the tabulation of replacement deposits on page 115 are three columns, designated respectively, ores, type, and examples. Except for iron, the types are lode, massive, and disseminated. For iron, they are magnetite, hematite, and limonite. One wonders why iron ore replacement deposits are classified on this different basis. Under cavity filling, original cavities and sub-

sequent cavities that serve as receptacles for ore are described, and the descriptions are amplified by a liberal use of illustrations. Included in this section is a discussion of ore shoots which is brief and confined to a consideration of the immediate causes operative at the loci of the shoots themselves. Although the *unsolved shoots* (those not so explainable) as yet defy interpretation, more remote and less direct causes are suggested by Penrose in his discussion of the ore shoots of Cripple Creek and in his chapter on "Some Causes of Ore Shoots" in *Types of Ore Deposits* which make their occurrence more understandable. The accounts of the processes of sedimentation, evaporation, and mechanical concentration do not require particular comment, other than to call attention to the fact that the titanium and monazite sands near Mineral City, Florida, were worked out several years ago. The mode of formation of residual deposits of iron, manganese, and aluminum ores is clearly presented and valid examples are cited. Placing the kyanite deposit at the Celo Mines in North Carolina among residual deposits, however, stretches the type to embrace any deposit, worked for minerals that resist weathering, which happens to have a weathered top.

Especially commendable is the section on oxidation and supergene enrichment. It is a very thorough description of these processes, and yet presented in clear style and in simple language, unencumbered by complex chemical equations. It includes the recent interpretations of limonite box-works. A few minor discrepencies may be disconcerting to students. The silicates of zinc are listed as ore-forming minerals diagnostic of oxidation, and the reader is referred to table 12 wherein willemite is listed as always hypogene. In the table on page 273, the carnotite beds of Colorado are erroneously placed in Gilpin County which has produced a little pitchblende, and the vanadium deposit of Minasragra, Peru, is classed as a residual deposit in which the oxidized ore is patronite which is the hypogene vanadium sulphide from which the oxidized ore minerals were derived. Furthermore, the zone of oxidation at Minasragra is no more properly classed as a residual deposit than would be the zone of oxidation of mineral deposits generally. The surprising statement on page 278 that no supergene gold enrichment is definitely known is contradicted in the table of important supergene enrichment deposits on page 288 in which four examples of gold enrichment are cited. The chapter on deposits formed by metamorphism includes only non-metallic minerals. Not entirely logical is the reasoning that leads to the suggestion that the fracturing of serpentine may be due to a decrease in volume rather than to an increase in volume accompanying serpentinization. The characteristic slickensiding of serpentine fractures is more indicative of expansion than contraction. Moreover, though serpentine replaces olivine, serpentinization is essentially a process of hydration wherein an anhydrous magnesium silicate is con-

verted to a hydrous magnesium silicate and is not strictly analogous to the kind of replacement commonly encountered by economic geologists which their experience shows is governed by the law of equal volumes.

In the chapter on Classifications of Mineral Deposits is a very brief historical account of the development of classifications culminating in Lindgren's classification, a discussion of the shortcomings of this classification, and a proposed substitute for it. As examples of classifications, based upon origin early in the 20th century, are tabulated the almost identical classifications of Beck 1904, Stelzner 1906, and Irving 1908. It is not clear why the date 1906 is given for the Stelzner classification since it was published in the first half of Stelzner-Bergeat *Die Erzlagerstätten* in 1904, and in the *Zeitschrift für praktische Geologie* in 1899 by Gürich as the classification that had been used by Stelzner in his lectures some years before. Beck adopted it with minor changes in his textbook in 1900, and Irving merely modified it in 1908 by separating contact metamorphic deposits from other replacement deposits, a separation actually carried out in the table of contents and in the systematic description of replacement deposits in Stelzner-Bergeat and the desirability of which was pointed out by Stelzner in 1880 in the Neues Jahrbuch in a review of von Groddeck's *Die Lehre von den Lagerstätten der Erze* (1879). Furthermore, the three cited classifications are essentially identical with von Groddeck's classification in 1879. The way for consistent genetic classifications was paved in the early 1890's by Vogt's classification of the magmatic segregations and pneumatolytic deposits. The first attempt at a complete consistent genetic classification appears to have been presented in 1903 by Weed. A similar classification was presented by Spurr at the same time. These classifications were published in 1903 by the Engineering and Mining Journal in a little volume with the title *Ore Deposits—A Discussion*, but received little attention. Much more widely known because of their publication in widely used textbooks, but not as consistently genetic, were the classifications proposed in 1909 by Beck and by Beyschlag, Krusch, and Vogt. The underlying principle of these classifications was to start from the magma as the ultimate source of the metals and set up types progressively further removed from the original magma source. Lindgren's classification in 1911 added temperature and pressure limits within which the types were formed. For some reason not explained he departed from the natural sequence away from the magmas by reversing the order and began with secondary deposits and progressed toward the magmatic source. There gradually grew into this classification the temperature and depth zone terminology which has come into such general use. Bateman points out several disadvantages and difficulties in the Lindgren classification. One is the fact that the type designations of some of the divisions are descriptions of the process

rather than names. Another is that more than one zone is frequently represented in a single district or even in the same vein. Still another is that to designate a deposit as mesothermal gives no word picture of whether it is a cavity filling, a massive replacement, or a disseminated replacement deposit. To overcome these objections, Bateman proposes a new classification in which the major divisions are the ore-forming processes described in his chapter on "Processes of Formations of Mineral Deposits." The classification has much to commend it. It is more practical at least for every day use. The subdivision of hydrothermal deposits, however, abandons the physical-chemical basis of their subdivision. It leads to placing such genetically unlike deposits as the Bassick pipe and the Mascot zinc deposits in the same subdivision because the locus of ore deposition in each case is a breccia. The sequence of the subdivisions of cavity fillings is a purely arbitrary enumeration of kinds of cavities instead of representing a progressive change in the physical condition of the ore fluid. It differentiates replacement deposits only on the basis of replacement lodes, massive replacement, and disseminated replacement, thereby placing in the same subdivision such geologically unlike deposits as the porphyry copper deposits and the Northern Rhodesia copper deposits because the ore minerals in each case are disseminated in the host rock. Nor is the classification of Rammelsberg as a metamorphosed deposit very enlightening. More fundamental is its history prior to metamorphism. Bateman rightly proposes it as a simple genetic classification for the use of students and practical mining geologists and operators. They will unquestionably find it more useful than Lindgren's classification. It will hardly be accepted as a satisfactory substitute by the scientific economic geologist.

Too much space has been devoted to Part I, to permit a detailed review of Parts II and III. In Part II deposits of the metals are described in four groups—the precious metals, the nonferrous metals, the iron and ferroalloy metals, and the minor metals and related nonmetals. As throughout the book, verbal descriptions are amplified by the liberal use of well chosen illustrations.

Part III affords striking evidence of the fact that not only has the twofold division of mineral deposits into metallic and non-metallic, but also the threefold division into metallic, non-metallic and fuels, more to defend it than "the ground of long established habit" charged against it by Lindgren. Coal is completely ignored and oil and gas are only considered incidentally in Part I. In Part III, only 17 pages are devoted to coal, 41 pages to petroleum and associated products, and 19 pages to ground water supplies, whereas 158 pages are devoted to industrial minerals and rocks. This weighting will not be satisfactory to the coal geologist, the petroleum geologist, and the hydrologist. On the other hand, students of

ore deposits and industrial minerals and rocks will find it convenient to have summary reviews of these branches of economic geology in a text designed primarily for their use. In Part II the deposits of the metals are classified and described strictly in accord with the classification and principles set forth in Part I. In contrast, on the introductory page to the non-metallic minerals, Bateman points out that specifications for the latter lack the constancy of metals and that the uses to which they are put are determining considerations in their valuation. Consequently a special classification of the non-metallic minerals based on both genesis and use is proposed. The use groups are mineral fuels, ceramic materials, structural-building materials, metallurgy and refractory materials, industrial and manufacturing materials, chemical materials, fertilizer minerals, abrasives, gemstones and ornamental, and water supplies. This mode of treatment distributes genetic units like the evaporites among several use groups and requires recurrence to the same material in several use groups. It gives a complete picture of a use group, but leaves a less definite picture of the individual product and especially of the geologic unity of groups of genetically related products. Calling attention to this result does not imply that the end does not justify the means, but does establish the fact that the division into metallic and non-metallic products is based on more than mere long established habit.

The effect of the omission of footnotes is not compensated for by the blanket acknowledgment in the preface. The service of footnotes is not primarily to give credit to the authors of sources of information but to refer the reader to the sources. For example on page 239, a footnote merely to acknowledge where Caillère stated his conclusions regarding the nickel silicate minerals would be of little value, but the reader might like very much to have such a footnote in order to know what the evidence for the conclusions is. In the case of prolific writers like Lindgren, whose work is spread over a wide range of literature and over a long range of time, it entails a most discouraging search to locate sources. The omission of footnotes is regrettable. It is doubtless one of the results of the stress under which the book had to be completed.

There is a surprisingly large number of typographical errors, the blame for which can not be laid to carelessness of the author. The date of the Preface is September 7, 1942. Long before that date, as chief of the Metals and Minerals Division of the Board of Economic Warfare, the author was overwhelmed by the magnitude and diversity of his important war duties and certainly had no time available for careful and calm proofreading. The fact that he was able to complete the book at all is striking evidence of his unusual energy and perseverence in pushing to completion whatever he undertakes. Many of the typographical errors are such

as an experienced proofreader should have caught, and the blame for them rests on the publisher.

Blending the trees again into the forest, the book is one of great merit and usefulness and is a worthy successor to Lindgren's *Mineral Deposits*. The author is to be congratulated on the job he has done, and economic geologists are fortunate in having the current status of the science so ably and so comprehensively presented to them.

JOSEPH T. SINGEWALD, JR.

THE JOHNS HOPKINS UNIVERSITY,
January 7, 1943.

The Floor of the Ocean. By REGINALD ALDWORTH DALY. Pp. 177, Figs. 82. Chapel Hill: The University of North Carolina Press, 1942. Price, $2.50.

This little volume, carrying the subtitle "New Light on Old Mysteries," consists of the Page-Barbour lectures given at the University of Virginia in 1941. Much of the material it contains has been presented earlier by the author in "The Architecture of the Earth," "The Strength and Structure of the Earth," and other volumes, but some is set forth for the first time. The combination has been rearranged and rephrased with the aim of making it readily intelligible to the non-geologist. In Daly's well-known lucid style it makes a book very stimulating to the geologist, although one may question whether a non-geologic audience could follow it at lecture pace. The concepts involved are profound, and the very magnitude of the features dealt with requires time for assimilation.

Chapter I, "Foundations of the Great Deep," deals principally with the constitution of the outer Earth-shells and the nature of the seismic evidence upon which their constitution is inferred. Chapter II, "Submarine Mountains," attempts to show that massive volcanic cones on the deep-sea floor are not loads that have made the crust yield notably. The author finds in the weakness of the substratum beneath a strong crust a prime condition for mountain making, and develops the theory of Vening Meinesz that the East Indian and West Indian arcuate chains are alpine chains in the making.

Chapter III, "Continental Terraces and Submarine Valleys," provides a valuable, concise review of the facts known about the great valleys that furrow the continental slopes, and a short critical summary of each of the chief hypotheses that have been advanced in explanation of their origin. The density-current theory, preferred by Daly, is then presented more fully, and its relation to glacial-eustatic movements of sealevel is ably pointed out.

In a series of three lectures it would be unfair for the reader (or listener) to ask for complete factual basis for each of the generalizations

drawn within them. But no one having some knowledge of the fundamental problems of geology can fail to read this volume without having new thought processes set in motion and his imagination profoundly stimulated.

R. F. FLINT.

Minerals of New Mexico. By STUART A. NORTHRUP. Pp. 387; Map. Univ. of New Mexico Bull. Geol. Ser. Vol. 6 No. 1. Univ of New Mex. Press, Albuquerque. Price, $1.00; de luxe, cloth bound, edit. $1.75.

This book contains a compilation of all the minerals occurring in New Mexico. The author has scoured the literature thoroughly and drawn upon a number of unpublished reports for his data. The first part of the book contains a short summary of the historical events affecting mining and mineralogy in New Mexico. The "highlights" of this historical summary begin with the advent of the first Europeans in New Mexico (1535) and their finding of turquois, and continues through 1942, a year which finds New Mexico participating in the intensive search for strategic and critical minerals made so urgent by World War II.

The bulk of the book is taken up by short but ample descriptions and records of occurrence of every known New Mexican mineral, 320 in all. The minerals are arranged in alphabetical order. This arrangement is the principal weakness of the book. A more desirable method probably would have been to arrange systematically the minerals according to the conventional classification and let the list in the appendix take care of the alphabetical order. Still, without such drastic revision, the author would have enhanced the value of the book as a reference work by having listed, within its present framework, the minerals according to their metal content and content of other economically important elements and compounds.

However, these are criticisms of detail and should not detract from the essential fact that here is a very useful work, obviously the product of thorough and arduous labor, which fills an important niche in the scientific literature. Two very helpful features of the volume are a comprehensive bibliography and a large map of New Mexico showing the counties and mining districts.

The author is to be commended for having included some interesting material on the archeological significance of certain minerals, especially turquois, and for generally having made the book of interest to as wide a public as possible. Mineral collectors, prospectors, archeologists, mineralogists, and geologists working in New Mexico will find this book a handy guide and reference.

HARRY M. MIKAMI.

BOOKS RECEIVED.

RALPH E. DIGMAN.

Among recent books received by the Journal on weather, climate and mapping are:

Climatology, General and Regional. By THOMAS A. BLAIR. Prentice-Hall, New York, 1942. Pp. xvi + 484; Figs. 102. Price, $5.00; special to colleges, $4.00.

This is an elementary book on the principles of climatology. The first part with brief, readily understandable definitions of terms, develops a simplified classification of climate and considers the influences exerted by climate on soils, land forms, plants, man and his activities. The second part consists of a concise summary of the main features of the major climatic regions of the world, taken up by continents, and is more interesting because "use of the tools" was learned in the first part. There is a good bibliography and index.

Meteorology and Air Navigation. By BERT A. SHIELDS. McGraw-Hill Book Co., New York, 1942. Pp. x + 285; Figs. 170. Price, $2.25.

Early in 1942 the author, a Lt. Comdr. U.S.N.R., published "Air Pilot Training." The purpose of the book was to present in a single volume "all the information necessary to pass the written examinations for a private and a commercial pilot license." Air Pilot Training has now been made available in two volumes and this volume covers meteorology and air navigation and takes up new types of problems recently required in the government written examinations for licensing pilots. Such a purpose, of necessity, extremely abbreviates the book and makes it pre-digested with real study of the "turmoil of weather changes" left to other meteologists. However, the author seems to be correct in his claim that "the subjects are presented in simple non-technical style, easily understood fundamental principles of physics and mechanics are clearly explained, and wherever technical terms are necessary a clear definition accompanies their first appearance in the text."

A number of elementary as well as some more advanced problems in navigation and their solutions are included and in addition an 8 page section of review questions.

Workbook in Meteorology. By A. F. SPILHAUS AND J. E. MILLER. McGraw-Hill Book Co., New York, 1942. Pp. 163; Charts 13. Price, $2.50.

This paper-bound loose-leaf book is just exactly what it is called—a workbook, consisting of a collection of exercises on report sheets which

may be removed from the book. Several copies of 13 different work charts are included in a back pocket. No claim is made for completeness although each exercise is preceded by explanatory material and references are given for collateral reading to permit working out the problems. The authors teach meteorology at New York University and have obviously used these exercises successfully in their own classes in elementary meteorology. Four subdivisions have been made: Mean Condition of the Atmosphere; Instruments and Methods of Observation; Exercises in Dynamical Meteorology; and Weather-Map and Upper Air Analysis.

Map Reading and Avigation. By P. M. FIELD AND H. T. STETSON. D. Van Nostrand Co., New York, 1942. Pp. xiii + 129; Figs. 88. Price, $2.50.

This book is likewise an elementary text which confines itself to essential material for introductory courses in map reading and avigation. The authors quote the delightful statement that "words bear about the same relation to things as a map does to the territory it stands for. Just as a map can never tell us everything about a territory, words can never tell us everything about anything." They make the well-chosen, simplified words they use tell a great deal and amplify with an enormous amount of excellent illustrative material in an experiment with a new method for teaching the fundamentals in the shortest possible time. Sufficient tables are included in the appendix to solve the problems.

Aerial Photographs: Their Use and Interpretation. By A. J. EARDLEY. Harper and Bros., New York, 1942. Pp. xxii + 203; Figs. 46; Pls. 46. Price, $2.75.

This book is the first in Harper's proposed Geoscience Series, edited by Cary Croneis who says that "although geologic aspects of the subject are featured, all applications of aerial photography are carefully considered, and the military importance of the use of these maps for tactical purposes is stressed." It is also another textbook developed for use in accelerated schedules to train as many people as quickly and as well as possible. The author teaches map-reading courses at the University of Michigan and has found considerable work on aerial photographs to be of great value and of particular interest to his students.

Material from the War Department's Basic Field Manuals on map and aerial photograph reading is included, but the largest portion of the book stresses the interpretation of geologic maps in conjunction with aerial photographs of the same areas.

Basic Principles of Weather Forecasting. By VICTOR P. STARR. Harper and Bros., Ne York, 1942. Pp. 299; Figs. 125. Price, $3.00.

This volume, "devoted exclusively to the problems of forecasting in the light of recent theoretical developments," is the second book in Harper's Geoscience Series. The author is in charge of the experimental weather forecasting unit at the Institute of Meteorology of the University of Chicago. He is particularly interested in making a weather forecast on data from a single station rather than on the basis of information from a network of stations. This has proved workable and is of extreme importance for military forecasts which must be made "on the spot," without benefit of information from many observation posts.

One chapter each is devoted to forecasting the actual weather during the four seasons of the year. Although the book stresses short-period forecasting, longer period forecasts are considered. It is well illustrated with new maps and charts.

E. M. W.

Geologic Importance of Calcareous Algæ with Annotated Bibliography. J. HARLAN JOHNSON. Pp. 102; Figs. 23. Colo. School of Mines Quart., Vol. 38, No. 1, Golden, Colo., Jan., 1943. Price $1.50. *Classification and splendid plates of calcareous algae preceeding a 70-page bibliography of American and foreign sources.*

The Geology of the Southern Part of Morton County, North Dakota. W. M. LAIRD AND R. H. MITCHELL. Pp. iv + 42; Figs. 7; Pls. 3. N. Dakota Geol. Surv. Bull. 14. Grand Forks, 1942. *Stratigraphy, physiography, and economic geology of the area.*

Twenty-Second Biennial Report. W. M. LAIRD. Pp. 9. N. Dakota Geol. Surv., Grand Forks, 1942. *Program, personnel, and financial statement of the survey.*

The Mines Magazine, Seventh Annual Petroleum Edition. Pp. 100. Mines Mag., Vol. 32 (10), Denver, 1942. Price, $1.00. *The annual petroleum edition of the magazine of the Colorado School of Mines Alumni Association. Contains 17 worthwhile articles.*

U. S. Geol. Surv., Washington, 1942. Professional Papers.

196-D **Geology and Biology of North Atlantic Deep-Sea Cores.** Pt. 5, Mollusca. HARALD A. REHDER. Pt. 6, Echinodermata. AUSTIN H. CLARK. Pt. 7, Miscellaneous Fossils and Significance of Faunal Distribution. LLOYD G. HENBEST. Pp. 17 + xviii; Fig. 1; Pls. 23. Price, 30 cents.

196-E **Geology and Biology of North Atlantic Deep-Sea Cores.** Pt. 8, Organic Matter Content. P. D. TRASK AND OTHERS. Pp. 14 + xviii; Figs. 9; Pls. 2. Price, 20 cents.

196-F **Geology and Biology of North Atlantic Deep-Sea Cores.** Pt. 9, Selenium Content and Chemical Analyses. GLEN EDGINGTON AND H. G. BYERS. Pp. 5 + xviii; Fig. 1; Pls. 2. Price, 15 cents.

SOCIETY OF ECONOMIC GEOLOGISTS

THE TWENTY-THIRD ANNUAL MEETING, NEW YORK CITY, FEBRUARY 15–17, 1943, HELD IN CONJUNCTION WITH AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS.

The technical sessions of the Society of Economic Geologists convened Monday afternoon, February 15, at 2:45 in the Engineering Societies Building. The sessions continued throughout the succeeding two days. There were presented 46 papers on various phases of applied geology and two papers were read by title. These sessions, as biennially customary, were held jointly with the Mining Geology Committee and the Industrial Minerals Division of the American Institute of Mining and Metallurgical Engineers. The program was published in full in ECONOMIC GEOLOGY, vol. 38, no. 1 (January–February 1943), pp. 76–79, and abstracts of many of the papers appear in the same issue, pp. 80–89, and in the current issue. The following paper presented by Mr. Heinrich was omitted from the published program mentioned above: "Structural and Mineralogical Features of Beryl-bearing Pegmatites," by L. R. Page, John Hanley, and E. W. Heinrich.

The annual business meeting of the Council was held on Tuesday, February 16, and decisions were reached which were reported at the business meeting of the Society the next day.

The annual business meeting of the Society, attended by approximately 100 members, was held at a dinner given at the Columbia University Club, New York City, on the night of February 17. This dinner was also the occasion of a joint meeting with the Geological Society of America at which the Penrose Medal of the Geological Society was presented to Professor C. K. Leith, past-President and past Penrose Medalist of the Society of Economic Geologists.

At the business meeting of the Society the Treasurer presented his report, which was accepted by vote. It was announced that the following were elected to office:

President for 1944
JOHN M. BOUTWELL

First Vice-President for 1944
OSCAR E. MEINZER

Councilors for 1943–1945

IRA H. CRAM — HUGH E. MCKINSTRY — SIDNEY PAIGE

Regional Vice-President for 1943

BEN LIGHTFOOT, *For Africa*
A. L. COULSON, *For Asia*
F. L. STILLWELL, *For Australia*
R. H. RASTALL, *For Europe*
MANUEL SANTILLAN, *For North America*
MANUEL TELLO B., *For South America*

The following were elected fellows of the Society: Frank R. Clark, Edward C. Dapples, Jr., Rukmini K. Dutta Roy, John L. Farrington, Daniel J. Fisher, Austin M. N. Ghosh, Sidney S. Goodwin, Thomas A. Hendricks, Waldemar I. Konkoff, Walter W. Moorehouse, Roy A. Morse, Robert J. Riggs, Stephen Royce, Lloyd J. Severson, Ward C. Smith, David St. Clair, Theron Wasson, Roy A. Wilson, Walter B. Wilson, Guillermo Zuloaga.

A brief review of the war work carried on by the fellows of the Society was given. The official meeting of the Society closed with a memorial to three fellows deceased during the past year; W. S. Bayley, Richard C. Cady, and Millard K. Shaler.

CHAS. H. BEHRE, JR.,
Secretary

Abstracts of Papers Presented at New York Meeting.

RESUMÉ OF PRE-WAR EFFORTS TO STOCKPILE.

WILLIAM Y. ELLIOTT.

Problems of stockpiling in the first year of the war consisted in uncontrolled shipping which did not permit sufficient imports, inadequate procurement programs, as well as the most serious outflow of supplies through lack of controlled uses in this economy and lack of adequate controls over exports. Since shipping priorities were made effective in the latter part of 1941, the problem of stockpiling has tended to become one of lack of world sources and of requirements outrunning available supply. At the present time, stockpile policy is of necessity limited to trying to keep imports, domestic developments, conservation and substitute programs ahead of the requirements of the United Nations. Fundamental questions raised as to future policy for stockpiles are two:

1. For how long a war should the stockpiles be built up, and at what period is it safe to begin drawing down the larger stocks?

2. Ought not provisions to be made by legislation at the present time to transfer from the R.F.C. agencies any stocks of non-perishable materials, except those of the character lending themselves to seasonal production at the end of the war to the status of Treasury Procurement (permanent) stockpiles?

The need for this is suggested by two reasons:

(*a*) To remove from the market the threat of government-held stocks which had a depressing effect after the last war both on production and on distribution, and

(*b*) To provide a permanent reserve of the world's exhaustible minerals whose sources lie in the main outside this country.

The world's most valuable materials would be locked up in such a way that they could not be objectionable to commercial interests or to the countries of supply which have heretofore been non-cooperative in building up stockpiles for fear that they would hang over the market; nor would it interfere with the normal channel of commercial trade for private import for current consumption.

MICA DEPOSITS OF GEORGIA.

GARLAND PEYTON.

Mica has been mined in Georgia since 1871, but mining activity in this connection has been spasmodic, with the greatest production occurring between 1902 and 1907 and during World War I. Total production from 1915 to 1940 was only approximately 500,000 pounds of sheet and punch mica and almost 20,000 tons of scrap mica, although evidence indicates that a large portion of the production was marketed through channels which did not make figures available for the records.

Production of commercial sheet mica has been confined to five principal areas: (1) The Lumpkin-Union-Towns County area; (2) The Rabun County area; (3) The Hart-Elbert County area; (4) The Cherokee-Pickens County area; (5) The Upson-Lamar-Monroe County area. Areas 1 and 2 are in the northeast corner of the State; area 3 is in the east-central portion of the crystallines adjacent to the South Carolina line; area 4 is about 50 miles north of Atlanta and just east of the Paleozoics; area 5 is located north of the Coastal Plain just north of the Fall Line, about 75 miles south of Atlanta.

The Upson-Lamar-Monroe is the most promising district and the scene of most of the mining activity at this time. Although the youngest area in point of mining activity, it has yielded the greatest quantity of high-grade sheet and punch mica within recent years. From this belt we obtain most of our ruby and rum hard flat mica. The Cherokee-Pickens and the Hart-Elbert are next in importance as possible producers of sheet and punch mica. These areas also yield some ruby or rum mica but with a tendency to show waviness and stain to a greater extent than in the preceding area. The Lumpkin-Union-Towns and the Rabun County belts, while probably older than any others in the State, do not yield as much high-grade strategic sheet and punch because of the tendency toward the occurrences of "A" mica and electric mica.

The foregoing statements are the indications which have resulted from recent field studies in more than 30 counties and including all of the areas described.

At present approximately 20 mines are producing from 1,200 to 1,500 pounds of sheet and punch mica of strategic grade per operating shift. This production can be increased to several times this amount with proper encouragement and cooperation, including higher prices for mica, federal loans for reopening and developing mines, the building of access roads, and making available experienced miners, timbermen, mechanics, blacksmiths, sheeters and classifiers. Other types of assistance would include provision of living accommodations for skilled workers' transfer from other places to the mines, transportation to and from the mines and to and from shopping centers, and improved facilities for leasing, exchanging, and repairing mine machinery and equipment.

ASBESTOS IN THE MILITARY PROGRAM.*

OLIVER BOWLES.

Asbestos is an irreplaceable material for certain important military uses. Brakebands and clutch facings for automotive transportation equipment fall in this class, but there is currently no shortage of asbestos for such

* Published with the permission of the Director, U. S. Bur. Mines.

uses. Packings and gaskets on warships, the merchant marine, and in numerous industrial plants are other important asbestos products for which adequate supplies of raw materials are available on the American continent. Low iron chrysotile needed for the more exacting electric insulating uses, and amosite, used for special types of lightweight insulation, are obtained only in Africa. Crocidolite or blue asbestos, another African product, is superior for high-pressure asbestos-cement pipe, acid-resistant packings, and certain specialized types of military equipment. As the United States produces only about 5 per cent of its total requirements of asbestos, foreign supplies are of the utmost importance. The Bureau of Mines, Department of the Interior, conducted in 1942 a monthly canvass of asbestos receipts, stocks, and consumption for the War Production Board. The situation at the end of the year was not critical.

*LITHIUM AND STRONTIUM IN THE WAR PROGRAM.**

CHARLES L. HARNESS.

Lithium: During World War I, most lithium salts were used in therapeutic mineral waters. Today two-thirds or more of the output is consumed directly in military operations. On the home front lithium chloride is used in air-conditioning, both in plants and offices. Lithium chloride and fluoride are employed as fluxes in aluminum welding, the hydroxide is used in Edison-type storage batteries, and the stearate is employed in aviation greases. Crystals of synthetic lithium fluoride are cut into lenses and prisms for special microscopical and other optical purposes. Lithium metal removes impurities from copper alloys and insures a sound casting, and in the vapor state the metal is used in muffle furnaces to neutralize the furnace atmosphere. Prior to March 1943 the Black Hills, S. Dak., area was the principal source of spodumene for lithium chemicals. After March 1943 the chief source is expected to be a quartz-spodumene rock found near Kings Mountain, N. C.

Strontium: The main use of strontium minerals is in tracer bullets and signal flares. The tracer mixture, which consists essentially of strontium peroxide and an oxidizable substance, is rammed into a hole in the base of the bullet. Strontium flares are available for almost any conceivable need, either military or civilian. Strontium parachute flares shot from a Very pistol are typical of distress signals at sea. Other strontium flares include hand flares, rockets, flares fired from submerged submarines, flares fired from rifles, and fusees used by railroads and trucking lines. Great Britain, Mexico, California, and Spain were the principal sources of chemical-grade celestite in 1942. Investigations of the Bureau of Mines indicate that much crude Texas celestite can be beneficiated easily to chemical grade.

* Published with the permission of the Director, U. S. Bur. Mines.

SCIENTIFIC NOTES AND NEWS

E. L. BRUCE of Queen's University, Kingston, Ontario, is the new president of the Geological Society of America.

R. F. FLINT is on leave from the Yale department of geology as a Major in the Army Air Corps.

A. M. HERON, formerly Director of the Geological Survey of India, is now economic geologist to the governments of Hyderabad and Iraq. He is in Hyderabad in winter and Iraq in summer.

W. C. KRUMBEIN of the University of Chicago department of geology is serving on the Beach Erosion Board of the War Department in Washington, D. C.

MAJOR R. C. CADY died January 15, at the age of 35 years, as the result of accidental injuries received while on duty overseas. For the past year he has served as a geologist in locating well sites to develop water supplies for military establishments of the United States Army in Africa and Asia. He was a member of the U. S. Geological Survey for twelve years. His most important research was on the Pleistocene and Tertiary geology and groundwater hydrology of the Great Plains.

At the banquet held during the Toronto meeting of the Prospectors' and Developers' Association February 12–13, J. B. TYRELL presented the collection of Logan medals to the Canadian Geological Survey. The medals, awarded by various governments and institutions to Sir William Logan, first director of the Canadian Survey, have been in Dr. Tyrell's custody and were presented to commemorate the 100th anniversary of the Survey.

H. O. WHITNALL, head of the department of geology and geography at Colgate University, instead of retiring this year is celebrating his fortieth anniversary as a faculty member by carrying an increased teaching load so that other members of his department can devote part of their time to classes in the newly established Naval Flight Preparatory School.

The Joint Annual Meeting of the American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists will be held at Fort Worth, Texas, April 7–9. This will be a War-Time Conference and A. I. LEVORSEN, chairman of the technical program, announces the sessions will be devoted to war reserves and discoveries.

F. D. ADAMS, author of *The Birth and Development of the Geological Sciences* and formerly head of the department of geology at McGill University, died on December 26, 1942.

J. G. BROUGHTON, formerly instructor in the Syracuse University department of geology, is assistant geologist for New York State.

DAVID GROSH THOMPSON, geologist in the Geological Survey, U. S. Department of the Interior, and one of the foremost authorities in the country on the development of water supplies from underground sources, died on February 19 at the age of 54 years.

J. K. GUSTAFSON of the Hollinger Exploration Co., Toronto, is now on the staff of Metals Reserve Co. in Washington, D. C.

J. H. JOHNSON, professor of geology at the Colorado School of Mines, was elected national president of the Society of Economic Paleontologists.

HAROLD MOORE, director of the British Non-Ferrous Metals Research Association, has been awarded the medal of the British Institute of Metal for "outstanding services to non-ferrous metallurgy."

H. J. RODDY, professor of geology and executive curator of the Museum of Franklin and Marshall College, has been made professor and curator emeritus.

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RARE ELEMENT PROSPECTING IN PEGMATITES.

T. T. QUIRKE AND H. E. KREMERS.

ABSTRACT.

The search for rare elements in pegmatites can be facilitated by applying chemical, physical, and mineralogical associations to the selection of a suitable test mineral which then may be expected to give clues as to the presence or absence of the rare element in the pegmatite. The characteristics and functions of certain test minerals are described.

The rare earths, columbium and tantalum, vanadium, and the rare alkalies are discussed with these points in mind.

INTRODUCTION.

IT is the purpose of this paper to point out an approach to the problem of prospecting for the rarer elements. This approach is based on the belief that the minor constituents of the relatively common, but not too common, minerals of a pegmatite will give clues as to the nature and mode of occurrence of the rare elements in the pegmatite and its geological associations. These test minerals must be of such nature as to afford a ready verification of the presence or absence of the element sought, and they must themselves be present in sufficient quantity to be easily found.

ASSOCIATIONS IN PEGMATITES.

For the purpose at hand, two kinds of chemical associations may be recognized in pegmatites: (1) those based on the similarity of certain chemical and physical properties of the elements, and (2) those based on the pressure-temperature-concentration relationships governing the order of crystallization of rock and pegmatite minerals.

Chemical and Physical Similarities. The grouping of the elements as presented in the Periodic Table of the atoms serves as a basis for one kind of similarity. For example, the rare earth elements are so much alike in their chemical properties that it is natural to assume that wherever one is found the others will also be found in greater or less amount. The alkalies are another obvious example. In general, it may be said that this type of association may be expected among those groups of elements that are chemically similar, *e.g.*, the alkalies, alkaline earths, rare earths, zirconium and hafnium, columbium and tantalum, etc.

A second kind of similarity between the elements is due to the relative sizes of the ions. During the formation of crystalline substances through the precipitation of ions, the developing crystal lattice acts as a sorting agent and allows only those ions of a limited range in size to take part as structural units in the lattice. Those foreign ions which have ionic radii (the radii of the atoms after they have become charged by ionization) closest to that of the ions forming the crystal lattice have preference over other foreign ions, but if the foreign ions have the same size but different valences, the one having a valence nearest to that of the ions forming the crystal lattice will have preference. As an illustration, consider the crystallization of rare earth magnesium nitrates ($2R(NO_3)_3.3Mg(NO_3)_2.24H_2O$) from an aqueous solution containing lanthanum, praseodymium, and neodymium. The first crystals to form will be enriched in lanthanum, since lanthanum magnesium nitrate is the least soluble constituent. Aside from the fact that neodymium magnesium nitrate is slightly more soluble than the other two salts, the lanthanum magnesium nitrate crystals will tend to be contaminated with more praseodymium than neodymium because the ionic radius of praseodymium is closer to that of lanthanum than is the ionic radius of neodymium (ionic radii: $La^{+3} = 1.00$ Å, $Pr^{+3} = 0.91$ Å, $Nd^{+3} = 0.90$ Å).

Order of Crystallization. A second type of association is based on the physical chemistry of igneous rock formation. The location of the element in the form of its mineral depends upon the original composition of the parent magma, and the pressure-tem-

perature-concentration relationships which determine the sequence of mineral crystallization in the pegmatite and its associated rocks. Certain elements not found in pegmatites to any great extent are sometimes found in other bodies which are associated with pegmatites but which originated under different conditions. Specifically, one should consider the whole range of deuteric, endomorphic, and contact metamorphism, and other processes involving the "fugitive" elements of magmatic origin.

Geological Associations. Goldschmidt's mineralogical phase rule admits one additional potential mineral for every element added to a system. As applied to the rare elements, this means that each rare element may occur in its own particular mineral. In certain cases the rare mineral possible would not be recognized without specific search for it, but with definite search it might be found. For statements of facts regarding mineralogical occurrences and associations, the present writers rely upon the works of Fersmann,[1] Gevers,[2] Landes,[3] and Niggli;[4] these authors agree essentially as to the conditions and order of development of pegmatite minerals, and they represent between them the larger share of professional opinion.

The interpretation of geological associations for the location of the rarer elements in the pegmatite requires that two factors be borne in mind: (1) the nature of the element as compared with other elements or groups of elements, and (2) the possibility that the element, under specific conditions, may form stable minerals conspicuously different from those characteristic of the group to which it normally belongs. In studying the first of these factors, reference should be made to the fundamental work of Goldschmidt on the ionic radii of the elements.[5] Reference must always be

[1] Fersmann, A. E.: Über die geochemisch-genetische klassifikation der granit-pegmatite. Mineral. und Petrog. Mitteilungen, 41: 64, 200, 1931.

[2] Gevers, T. W.: The pegmatite area south of the Orange River in Namaqualand. S. Africa Geol. Surv. Mem. 30, 1937.

[3] Landes, K. K.: Origin and classification of pegmatites. Am. Min. 18: 33, 95, 1933.

[4] Niggli, P.: Lehrbuch der Mineralogie. Gegrüber Borntrager, Berlin, 1920.

[5] Goldschmidt, V. M.: The principles of distribution of chemical elements in minerals and rocks. Jour. Chem. Soc., 1937, pp. 655–673.

made to the mineralogy and to a general knowledge of the chemistry of the rarer elements in order to evaluate the various modes of occurrence.

APPLICATIONS OF ASSOCIATIONS.

To illustrate this method of approach, the rare earths, and columbium and tantalum are discussed below with the view of predicting their probable existence as ore minerals on the basis either of their actual occurrence in other minerals, or of the presence of closely related elements in other test minerals. Vanadium is discussed with reference to its occurrence in titaniferous magnetites, and the rare alkalies are noted as found in pegmatites.

The Rare Earths.[6] The most important rare earth mineral is monazite, a phosphate of the rare earths. Since monazite is found in the high temperature zones of the pegmatite and is one of the first minerals to precipitate, it is at once apparent that small crystals of the mineral will be found as inclusions in other later minerals if the original magmatic solution contained appreciable quantities of the rare earths and sufficient phosphates. The presence of apatite in the pegmatite would indicate that there was an abundance of phosphates at the time of formation of the monazite. Since the rare earths, especially the cerium earths, are known to be capable of replacing calcium (ionic radii: $Ca^{+2} = 1.06$ Å, $Ce^{+4} = 1.02$ Å), it is logical to select apatite as a probable test mineral since it contains both calcium and phosphates. Therefore, if the apatite molecule contains rare earths, or if the apatite mineral contains inclusions of rare earth phosphates (for instance, small crystals of monazite), it is only logical to assume that monazite may be found in the higher temperature zones of the pegmatite. However, the mere presence of rare earths in the apatite may not be a certain guide to useful deposits since it is possible that there may always be a limited concentration of rare earths in apatite. Some idea as to the values to be expected is

[6] The rare earths consist of thorium, yttrium, scandium, and elements 57 to 71 inclusive.

available from published analyses.[7] For instance, apatite from Kingston, Ontario carries 0.27–0.46 per cent rare earths, whereas apatite from Renfrew, Ontario, shows 2.27 per cent rare earths. These differences perhaps reflect the relative content of rare earths in the associated pegmatites in these localities. In cases where a concentration higher than normal is found, the development of monazite should be expected.

In the usual case where apatite occurs only as small euhedral crystals, monazite inclusions within the apatite may be detected by microscopic examination in specimens from the parent granite. The next step would be to prospect for the high temperature pegmatite bodies associated with that granite, where monazite should be expected to have crystallized.

As a practical matter, commercial deposits of monazite may be found only where running water has effected a still further concentration into placer deposits, as in India and Brazil, but these deposits must depend upon the pegmatite assemblage for their source of monazite.

Another important rare earth mineral is orthite or allanite, a hydrated silicate of calcium, ferrous and ferric iron, beryllium, aluminum, and the rare earths. If the pegmatite contains inadequate phosphate to develop apatite, the logical test mineral next to seek is a silicate, preferably some suitable variety of epidote, especially orthite or allanite. Wherever allanite is found, more rare earths may have combined with most, if not all, of the phosphate in the magmatic solutions and hence may be found also as monazite in the higher temperature phases of the same rock assemblage. In Alexander County, North Carolina, there appears to be such a rock and pegmatite assemblage, providing both allanite and monazite.

At this time, many geologists are noting the specific qualities of zircons found both in igneous and in sedimentary rocks. Zircon varies from magma to magma so definitely that the variations of zircon crystals can be used in order to distinguish between zir-

[7] Starynkevich-Borneman, I. D.: Sur le présence des terres rares dans les apatites Compt. Rend. Acad. Sci. Russie, 1924, pp. 39–41; Min. Abs. 2: 408, 1925.

cons which originate in different magmas. These examinations might be extended to the thorium and rare earth content of zircons, especially since zircon (zirconium silicate) and thorite (thorium silicate) are isomorphous. Accordingly, we should add zircon (especially the cyrtolite variety) to the list of rare earth test minerals.

Columbium and Tantalum. Many columbium and tantalum minerals are quite complex and are formed under rigorously controlled conditions at relatively high temperatures. In view of these facts, the most logical places to look for columbium and tantalum are in complex pegmatites containing relatively high-temperature minerals. Many chemically unrelated minerals, none of which are very common, are precipitated under similar conditions (for example, beryl, spodumene, topaz and zircon). Where any of these occur, search should also be made for columbium and tantalum minerals. For the same reasons, high-temperature metamorphic deposits should also be examined, especially greissen, schorl, and other "contact" mineralizations.

Columbium and tantalum show considerable resemblance to titanium. As a matter of fact, a little titanium is always present even in tantalite, $(Fe,Mn)O.Ta_2O_5$, and columbite, $(Fe,Mn)O.Cb_2O_5$.[8] In the so-called euxenite pegmatites[9] of course titanium is an important constituent with columbium and tantalum in all minerals of the euxenite group. Of the titanium minerals, titanite (essentially calcium titanate) may be serviceable as a test mineral because it is formed under the same conditions as are columbium and tantalum minerals and is easily recognized in pegmatites and contact rocks. Titanite has the further advantage of being relatively common. It is to be expected that most titanite examined would show no appreciable content of the rare elements, but in cases where titanite does contain appreciable quantities of them, of course the rarer minerals should be looked for. From a comparison of the ionic radii of columbium and titanium (ionic radii: $Cb^{+5} = 0.69$ Å, $Ti^{+4} = 0.64$ Å) and from the fact that

[8] Ellsworth, H. V.: Rare-element minerals of Canada. Canada Geol. Surv., Econ. Geol., Ser. No. 11: 26, 1932.

[9] *Ibid.*, p. 119.

columbium and tantalum tend to exist in anions (forming columbates and tantalates), as does titanium in titanite, the use of titanite as a test mineral seems reasonable. On the other hand, rutile would not serve as a test mineral because titanium here is held in the cation. Ilmenite, $TiO_2.(FeO)_x.(Fe_2O_3)_y$, might be suggested as a test mineral because of its titanium content. However, columbium and tantalum form anions (columbates and tantalates) of a definitely acid character; titanium in ilmenite is probably held in the cation, and occurs commonly in basic magmatic segregations. Analyses by v. Hevesy, Alexander, and Würstlin [10] show that the content of columbium and tantalum in rutile and titanite varies greatly in different localities, but that there is almost no columbium and tantalum prevailingly in ilmenite. Consequently, ilmenite is useless as a test mineral for columbium and tantalum, but titanite may be of some value. This case illustrates the general chemical rule that elements are associated not only as to ionic radius but also as to ionic charge (valence).

Certain minerals show a close association of zirconium and columbium. These are highly complex molecules formed in complex pegmatites and may properly be accounted for as fortuitous associations of zirconium and columbium rather than as chemical relationships. Such cases are in contrast to the association of zirconium and thorium in zircon, which is isomorphism. Zircon can hardly be expected to be a test mineral for columbium and tantalum in a chemical sense, but it may accompany physical conditions suitable for the precipitation of columbium and tantalum provided they are present. On the other hand, zircon which contains thorium in any sort of pegmatite indicates the probable presence of rare earth elements. Many of the rare earth minerals are columbate-tantalate-titanates; thorium-bearing zircon may accordingly indicate the occurrence of columbium and tantalum in the complex phases of the same pegmatite assemblage as euxenite or some other rare mineral.

[10] v. Hevesy, G., Alexander, E., and Würstlin, K.: Über das Häufigkeitsverhältnis Niob-Tantal in Titanmineralien. Zeit. für anorgan. und allgemeine Chemie, 181: 95–100, 1929.

Vanadium. Although vanadium is not found to any great extent in pegmatites, the authors wish to point out the fact that vanadium minerals are known as later introductions of basic magmatic segregations. Dunn and Dey [11] found vanadium as the mineral coulsonite, $(Fe,V)_2O_3$, dispersed in the magnetite of titaniferous magnetites in Singhbhum and Mayurbhang, India, and similar occurrences have been reported on this continent.[12] Dunn and Dey observed that the vanadium content of the titaniferous deposits was larger than that of the non-titaniferous deposits, but there was no systematic relation between the vanadium and titanium contents. Although the relation here between vanadium and titanium is not clear, it is probable that vanadium and titanium were intimately associated in the parent magma, but that in the formation of the titaniferous magnetite certain chemical relationships, the nature of which are uncertain, determined the destiny of the vanadium.

On the basis of ionic radii: $V^{+5} = 0.59$ Å, $V^{+4} = 0.61$ Å, $V^{+3} = 0.66$ Å, $Ti^{+4} = 0.64$ Å, $Fe^{+3} = 0.67$ Å), trivalent vanadium might well replace tetravalent titanium, but this does not happen. Trivalent vanadium is even closer to ferric iron than to tetravalent titanium, and apparently this at least in part explains the formation of coulsonite. However, the ionic radius relationships of titanium and vanadium may be some explanation for their association in the parent magma. Apparently, in the late magmatic stages, the titanium was deposited in solid solution with magnetite. Meanwhile, vanadium seems to have been retained in the residual magma as a minor constituent until lower temperatures were reached. Finally, it was expelled and replaced part of the earlier magnetite, forming coulsonite. This may have been effected by the replacement of ferrous oxide by either the tetroxide or the

[11] Dunn, J. A., and Dey, A. K.: Vanadium-bearing titaniferous iron ores in Singhbhum and Mayurbhang, India. Min. and Geol. Inst. of India Trans. 31: 117, 1937.

[12] The authors are under obligation to W. C. Lacy who kindly advised them regarding his own discovery of coulsonite in the highly metamorphosed rocks of the Parry Sound District of Ontario. Coulsonite occurs here in magnetite associated with ilmenite, but not in the ilmenite.

pentoxide of vanadium, producing thereby ferric oxide and a corresponding sesquioxide of vanadium according to the following equations:

$$(1)\quad 2FeO + V_2O_4 = \underbrace{Fe_2O_3 + V_2O_3}_{\text{coulsonite}}$$

$$(2)\quad 4FeO + V_2O_5 = Fe_2O_3 + \underbrace{Fe_2O_3 + V_2O_3}_{\text{coulsonite}}$$

A study of the writing by Dunn and Dey [13] convinces any reader that the relations of titanium dioxide to ferrous and ferric iron are very complex. Nevertheless, it seems clear that the ilmenite occurs with a hematite-rich magnetite assemblage. Apparently, later in the mineralizing process both hematite and ilmenite have separted from an original solid solution with magnetite. The original solutions must have been definitely oxidizing, quite aside from evidences of weathering. Certainly there are two generations of magnetite, followed by coulsonite which avoids ilmenite, even where ilmenite and magnetite are graphically intergrown. Some association of hypogene hematite and coulsonite is noted. Lacy [14] reports that hematite occurs as intergrowths with the ilmenite in magnetite associated with coulsonite at Lake Sanford, New York, and that later subordinate veinlets of hematite replace ilmenite and magnetite in the Parry Sound area. It occurs to the present writers that part of the association of hematite and coulsonite may be genetic.

Since the earlier magnetite apparently was in a partly oxidized state, presumably the magmatic vanadium was in the pentavalent state. That being so, the deposition of coulsonite by the replacement of magnetite might release ferric oxide to crystallize as specular hematite under the conditions which should be expected to prevail at the time of replacement (equation (2) above). However, lack of geological proof of this possibility leads to the suggestion that coulsonite itself with a theoretical $Fe_2O_3:V_2O_3$ ratio of 1 : 1 may well take on any additional ferric oxide which might de-

[13] Op. cit., pp. 137–160.

[14] Lacy, W. C., Private communication.

velop from the reduction of pentavalent vanadium. In such a case we should not expect syngenetic hematite with coulsonite, and this seems to be the rule.[15]

It must be emphasized that these remarks concerning vanadium apply only to high temperature deposits and are not applicable to low temperature and sedimentary deposits where the conditions of precipitation are entirely different, and wherein vanadium is generally pentavalent.

Rubidium and Cesium. Stevens and Schaller [16] have recently published a study of the rare alkalies in mica. They show that the rare alkalies rubidium and cesium are most abundant in the micas of the lithium phase of pegmatites. There is a definite association of lithium, rubidium, and cesium, but the quantitative ratio between the three alkalies varies widely from locality to locality. Nevertheless, lithium-bearing pegmatites ordinarily contain some rubidium and cesium in biotite and lepidolite. Lepidolite is a very useful guide mineral in the search for rubidium and cesium because its unusual purple or lilac color makes it easily identified in the field, as compared with lithium-bearing biotite which is indistinguishable in appearance from biotite containing no rare alkalies.

In this case lepidolite serves as an indicator of rubidium and cesium by virtue of its content of potassium which is chemically akin to rubidium and cesium. The ionic radii of the alkalies (ionic radii: $Li^+ = 0.78$ Å, $Na^+ = 0.98$ Å, $K^+ = 1.33$ Å, $Rb^+ = 1.49$ Å, $Cs^+ = 1.65$ Å) indicate that lithium is more likely to occur with sodium, and that rubidium and cesium are more similar to potassium than to either sodium or lithium. The analyses of Stevens and Schaller indicate that the sodium mica paragonite has less of the rare alkalies than have the high potassium micas. Admittedly the number of analyses is less than one might wish, but

[15] In a personal communication Mr. J. R. Balsley, Jr., advises that no hematite can be seen in the vanadium-bearing titaniferous magnetites he has examined. H. V. Ellsworth states in a personal communication that he has not noticed hematite in Canadian vanadiferous-titaniferous magnetites.

[16] Stevens, R. E., and Schaller, W. T.: The rare alkalies in mica. Am. Min. 27: 525, 1942.

as such they indicate the association of rubidium and cesium with potassium rich micas. Lepidolite may be more useful as an indicator of significant physical conditions than of chemical relationships. Lepidolite is formed during the lithium pegmatite stage [17] in which rubidium and cesium seem to be coerced into precipitation with other alkalies, especially potassium.

The authors wish to point out the fact that although rubidium and cesium are introduced into the pegmatite with lithium, the final location of rubidium and cesium in minerals depends upon their association with potassium and not with lithium, as the ionic radii of these elements indicate. This point is brought out even more clearly if we refer to Bragg's [18] discussion of the structural place of lithium in lepidolite. Following Mauguin, he explains that the electropositive atoms in the micas may be classed into three oxygen coordination groups of 4, 6, and 12. Only the smallest atoms can be enclosed by four oxygens, the medium by six, and the larger by twelve. In the case of lepidolite Bragg assigns lithium to the 6-oxygen coordination group together with aluminum. All the other alkalies have to remain with the 12-coordination elements. Only lithium seems to be sufficiently small in ionic radius to crowd itself into a 6-coordination space. Inasmuch as cesium and rubidium have ionic radii larger than those of the other alkalies, they are the least able to accompany lithium into the 6-coordination space. They must be associated with potassium, which is invariably in the 12-coordination group in micas. Consequently, in lepidolite itself there appears to be a sharp structural separation of lithium from the other alkalies and a correspondingly close association of the rare alkalies with potassium.

This collection of rare alkalies by the late-forming potassium micas of the pegmatite recalls the fact that *late* crystals of potassium feldspars in pegmatites carry considerable amounts of rubidium, cesium, and thalium [19] without regard to lithium. Never-

[17] Stevens, R. E., and Schaller, W. T.: op. cit., p. 533.

[18] Bragg, W. L.: Atomic Structure of Minerals. Cornell Univ. Press, 1937. Pp. 214–216.

[19] Goldschmidt, V. M.: op. cit., p. 661.

theless, in field examinations the feldspars offer no visible indications as to whether or not appreciable quantities of the rare elements are occluded. The feldspars, therefore, like the biotites, are not suitable test minerals for the rare alkalies. Lepidolite seems to have unique usefulness with respect to rubidium and cesium as a test mineral. Not only does lepidolite itself usually carry the rare alkalies, but it indicates their presence also in the associated syngenetic biotites and potassium feldspars.

Provided the analysis of lepidolite indicates more than a common content of cesium, then one should look definitely for the rare mineral pollucite (cesium aluminum silicate), because the addition of one extra component, cesium, justifies the expectation of a corresponding increase in the number of minerals, according to the mineralogical phase rule. Rubidium also would theoretically require another additional mineral in which rubidium is an essential constituent; such a mineral is rhodizite.[20]

DISCUSSION.

In many cases the minerals of the rarer elements which occur in pegmatites are not easily found and are often overlooked. If indications of these elements can be found in more abundant minerals which are common to many phases of a pegmatite assemblage, the search can be greatly helped. The finding of evidence of these elements in the test minerals in any phase of the pegmatite should lead to the search for rarer minerals containing these elements in specific phases of the same pegmatite assemblage; this follows from the mineralogical phase rule. All this depends upon the following premise: traces of the rare elements occur in commoner minerals in proportion to the extent to which they occurred in the parent magma. On the basis of the accepted theories of pegmatite origin and the known facts concerning the associations of the elements, particularly with regard to the role of ionic radii in the formation of crystallline substances, it is reasonable to believe that this premise is sound.

[20] Rhodizite is a borate of aluminum, potassium, cesium, and rubidium. Cesium is present in minor quantities. Rhodizite is found in pegmatites in Madagascar. See Ellsworth, op. cit., p. 12.

The method of spectrographic analysis would be of great help in examining the test minerals selected for the search. Using qualitative spectrographic analyses, Bray [21] was able to distinguish and correlate various rock bodies in Tertiary dike rocks of the Front Range, Colorado. He found that certain of the rarer elements occurred in rocks in different quantities and that the various mineral species were characterized by specific ratios between certain rare elements. By the examination of specific minerals, which he called "index minerals," collected from a variety of rocks, he was able to correlate or distinguish the rocks. Our suggestion is that certain minerals should be examined, according to the element sought. These minerals then become test minerals in prospecting for the elements desired in that particular rock assemblage.

The test mineral must neither be too common, since this greatly extends the field of association, nor must it be too rare, for in this case the problem could be solved more easily by searching directly for the rare mineral itself. It should be formed contemporaneously or immediately following the desideratum. The test mineral should contain adequate contamination of the rare elements for an approximation of its quantity, even by spectrographic analysis. Careful search will probably reveal many more occurrences of the rare elements in test minerals than are now recorded, with the result that for each rare element it will become apparent that only certain degrees of concentration will be significant for prospecting.

As aids to the solution of problems of this kind, it is suggested that the following points be borne in mind:

(1) Ionic radii and their possible effect on mineral replacement.
(2) The element may occur as an anion (columbium and tantalum, for example, form columbates and tantalates), or as a cation, or the element may be amphoteric.
(3) Relation to other elements, especially with regard to those having a tendency to form complex molecules. The micas

[21] Bray, J. M.: Distribution of minor chemical elements in Tertiary dike rocks of the Front Range, Colorado. Am. Min. 27: 425, 1942.

are notable in this respect. They are complex structures in which certain alkali metals readily substitute for one another.

(4) Isomorphism of crystalline substances.

(5) Physical chemistry of pegmatite formation. This involves (*a*) the composition of the original magmatic solutions, and (*b*) pressure-temperature-concentration relationships which determine the order of crystallization of pegmatite minerals.

SUMMARY.

Certain chemical and mineralogical associations of the elements have been proposed as a guide to the location of deposits of rare minerals in pegmatites. The rare earths, and columbium and tantalum have been discussed from the standpoint of prospecting by the examination of test minerals in pegmatites. Titaniferous magnetites should be examined for vanadium as coulsonite, as previously recommended by Dunn and Dey.[22] Stevens and Schaller show that lepidolite is a test mineral for the rare alkalies in the "lithium stage" of pegmatites.

A satisfactory test mineral must not be too abundant, or too rare in the pegmatite, and it should be capable of occluding detectable traces of the minerals or elements sought after, either by mechanical occlusion, or by means of association based on the similarity of some particular property of the desired element to the elements which compose the test mineral. From a study of the chemical and mineralogical properties of the rare element sought after, it should be possible to develop a plan for the search of a relatively abundant mineral, analysis of which would indicate the presence or absence of the rare element, and thus facilitate the field work.

We conclude that:

(1) Apatite should be a test mineral for the rare earths.

(2) High temperature epidotes are test minerals for the rare earths.

(3) Zircon is a test mineral for thorium; it may be useful with regard to the rare earths, and columbium and tantalum.

[22] Op. cit., p. 161.

(4) Titanite is thought to be a test mineral for columbium and tantalum.

(5) Lepidolite is a first-class test mineral for the rare alkalies in pegmatites.

(6) Ilmenite is a test mineral for vanadium in magnetite.

(7) The same principles may be applied in the search for other rare elements.

ACKNOWLEDGMENT.

The authors are indebted to H. V. Ellsworth, W. T. Schaller, and Wm. F. Bradley for reading the manuscript, and for various helpful suggestions which have been used in revisions. Dr. R. Steinman cooperated in closely related contributory studies.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS,
December 10, 1942.

CHEMICAL LIME IN CENTRAL PENNSYLVANIA.

G. MARSHALL KAY.

ABSTRACT.

High-grade limestone is present in several Middle Ordovician formations in Central Pennsylvania, but only the Valentine member of the Curtin formation has sufficient thickness for large-scale removal. The Valentine is restricted to outcrop belts northwest of a line from east of Lock Haven and Rebersburg to north of Millheim, Spring Mills, Lemont and Stormstown, in Clinton and Centre counties. The maximum thickness is 90 feet at Bellefonte, the upper 65 feet having less than two per cent of non-carbonate. Regional unconformity at the base of the overlying Nealmont limestone gradually reduces the unit toward the line of extinction, restricting the area having important thickness of stone. Moreover, the Valentine is considerably reduced in about 10 per cent of the area of outcrop in the Bellefonte district by channels filled with Nealmont limestone. Much of the stone has been removed from the most favorable areas of outcrop, but a large reserve is available to mining.

INTRODUCTION.

CHEMICAL lime can be obtained from several of the units in the middle Ordovician of Central Pennsylvania. The rocks outcrop on the limbs of the folds of the regional anticlinorium, the largest structure being the Nittany anticline (Fig. 1). The local structure of a part of the area has been mapped in the Bellefonte [1] and Tyrone [2] quandrangles. The sequence of the economically important limestones is as follows: [3]

[1] Butts, Charles, and Moore, E. S.: Geology and mineral resources of the Bellefonte Quadrangle, Pennsylvania. U. S. Geol. Surv., Bull. 855, 1936.

[2] Butts, Charles, Swartz, F. M., and Willard, Bradford: Tyrone Quadrangle, geology and mineral resources. Penna. Geol. Surv., 4th ser., Atlas No. 96, 1939.

[3] Kay, G. M.: Middle Ordovician formations in Central Pennsylvania (abstract). G. S. A. Bull., 52: 1969, 1941, with some revision.

Series / Group / Formation / Member	Thickness at Union Furnace	Thickness at Bellefonte
Mohawkian		
Trenton		
Salona limestone		
Nealmont limestone	139 ft.	50–90 ft.
(regional unconformity)		
Black River		
Curtin limestone		
Valentine limestone *	absent	20–90 ft.
Valley View limestone	absent	50 ft.
Benner limestone		
Stover limestone	91 ft.	70 ft.
Snyder limestone *	98 ft.	75 ft.
Chazyan		
Hatter formation	102 ft.	75 ft.
Loysburg formation		
Clover limestone *	64 ft.	75 ft.
Unclassified limestone and dolomite		

* Units containing high-grade limestone.

All the limestones except the siliceous upper (Hostler) member of the Hatter formation, the upper (Rodman) member of the Nealmont limestone, and the argillaceous Salona limestone have been utilized for blast furnace flux in the past. Though the Clover limestone and Snyder limestone contain limited quantities of stone suitable for chemical lime, and have furnished stone for local lime-kilns, they are not promising as sources for large quantities of lime. The Valentine limestone is the principal producing unit. The strata have been included in the "Lowville limestone," [4] a unit that included in several areas, parts of the Nealmont, and the Snyder, Stover and Valley View limestones. The relatively pure chemical limestone has been considered to pass laterally into stratigraphically equivalent lower grade limestone.[5] The writer has concluded that the Valentine is a distinct and constant lithologic unit, restricted in distribution by a regional unconformity bevelling its top, locally reduced in thickness by channels over-

[4] Butts, Charles, and Moore, E. S.: op. cit., 1936.

[5] Field, R. M.: The Middle Ordovician of Central and South Central Pennsylvania. Amer. Jour. Sci., 4th ser., 48: 403–428, 1919.

lying the unconformity, and that strata that have been considered stratigraphically equivalent are of different ages.

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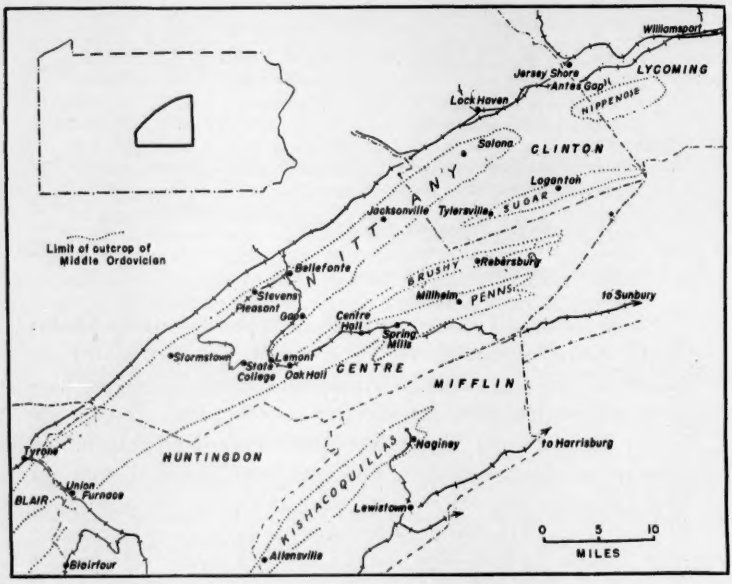


FIG. 1. Map showing localities in Central Pennsylvania.

and A. C. Hewitt of the American Lime and Stone Company, Bayard Magee of the National Gypsum Company, and R. C. Noll of Whiterock Quarries, all of Bellefonte; and by Professor W. H. Myers of Pennsylvania State College.

GENERAL STRATIGRAPHIC RELATIONS.

The chemical lime is gained from stratigraphic units that are lithologically quite constant throughout Central Pennsylvania.

The characters of the formations in single sections are representative of those in others. All but the Curtin formation are represented in the section on the two sides of the Pennsylvania Railroad cut north of Union Furnace, and in the east quarry of the American Lime and Stone Company at Pemberton, to the north; the measurements are principally from the former locality (Table I). The Curtin limestone is absent at Union Furnace through the presence of a regional unconformity that brings the lower Trenton Nealmont limestone upon successively older units southeastward, until its equivalent, the Mercersburg limestone, lies on rocks older than the Benner limestone in the vicinity of Chambersburg, Franklin County[6] (Fig. 2). The Curtin and adjoining

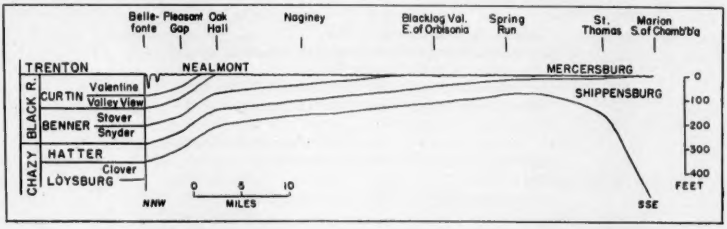


FIG. 2. Outline restored section of pre-Trenton Middle Ordovician limestones, southward from Bellefonte.

limestones are exposed near the headframe of the Bell Mine of the American Lime and Stone Company at Bellefonte (Fig. 3); the section (Table II) is similar to that published by Rosenkrans,[7] who assigned the designations to the metabentonites. The units from the "tiger-stripe" member of the Loysburg formation to the lower Valentine limestone are well exposed in the entrance cut to quarry number 23, west of Stevens. The succession is: Loysburg formation—Clover limestone, 78 feet; Hatter formation—Eyer member absent, Grazier and Hostler members, 28 and

[6] Kay, G. M.: op. cit., 1941. Craig, L. C.: Middle Ordovician of the Chambersburg region, Pennsylvania. G. S. A. Bull., 52: 1963–1964, 1941.

[7] Rosenkrans, R. R.: Correlation studies of the Central and South Central Pennsylvania bentonite occurrences. Amer. Jour. Sci., 5th ser., 27: 113–134, 1934.

TABLE I.

SECTION AT UNION FURNACE, PENNSYLVANIA.

Description of formation	Thickness	
	Unit Ft. In.	To base Ft. In.
ORDOVICIAN SYSTEM		
MOHAWKIAN SERIES		
TRENTON group		
Salona limestone (Field, 1919):		
Dark, dense, plane-bedded limestone with black shale interbeds, containing several metabentonites, "0" near the base		
Nealmont limestone (Kay, 1941 *):		
Rodman member (Butts, 1918):		
Dark, brown-weathering, rather heavy-ledged, siliceous limestone, with some black chert	22 3	139 0
Unclassified members:		
Dark, dense, thin-bedded limestone with heavier interbeds; quite fossiliferous	92 1	116 9
Heavy ledge, of coquinal and of dark, coarse-textured limestone with *Columnaria* sp.	3 9	24 8
Heavy ledges of principally thin-bedded, dense limestone, with interbeds of thicker, mottled limestone and calcarenite	17 4	20 11
Dark, coarse-textured, impure limestone, having a somewhat irregular base, in two ledges	3 7	3 7
BLACK RIVER group		
(disconformity; Curtin formation absent)		
Benner limestone (Kay, 1941)		
Stover member (Kay, 1941 *):		
Ledge of dark, mottled limestone	1 2	91 1
Gray, fine-textured limestone, partly thin-bedded, with lenses of calcarenite and limestone conglomerate; contains *Distactyospongia* sp.	6 6	89 11
Heavy ledges of thin-bedded, dark limestone, with thin calcarenite beds and some black chert; *Stromatocerium* near the top	13 7	83 5
Metabentonitic clay "F," sheared, thinning and swelling; exposed on both sides of railroad cut	0 6	69 10
Heavy ledges of dark, fine-textured limestone with wavy, silty partings and thin calcarenite beds; *Cryptophragmus antiquatus* Raymond and *Distactyospongia* sp. at 37 and 55 feet from the base	69 4	69 4
Snyder member (Kay, 1941 *):		
Somewhat granular limestone with *Tetradium cellulosum* (Hall)	1 4	97 10
Medium- to coarse-textured detrital limestone, having white limestone pebbles	16 4	96 6
Fine- to medium-textured limestone, partly thin-bedded, gray and buff-weathering, with limestone conglomerate; *Girvanella*-bearing conglomerate at top repeated by small fault	21 9	80 2

TABLE I—*Continued*

Description of formation	Thickness	
	Unit Ft. In.	To base Ft. In.
Interbedded coarse-textured limestone with white-weathering limestone pebbles, and sublithographic limestone, "chemical lime"; *Tetradium fibratum* Safford abundant in upper 6 inches, *T. cellulosum*, 4 feet from base	21 8	58 5
Laminated and partly cross-bedded detrital limestone with pebbly interbeds	25 10	36 9
Gray, medium-textured, laminated, somewhat mud-cracked and rippled limestone, with white-pebble conglomerate at top	8 7	10 11
White-weathering, dense, well-bedded limestone with deep shaly reentrant at base; contact concealed	2 4	2 4
CHAZYAN SERIES		
Hatter formation (Kay, 1941 *)		
Hostler member (new *):		
Dark, impure, well-bedded, somewhat laminated limestone, sparsely fossiliferous	21 0	102 0
Dark, tan-weathering, siliceous and argillaceous limestone, massive in fracture, richly fossiliferous, less impure near base	42 0	81 0
Grazier member (new *):		
Dark, dense, heavy-ledged limestone with wavy, argillaceous partings, stylolitic, tending to weather with rows of holes; relatively non-fossiliferous	33 0	39 0
Eyer member (new *):		
Dark, impure limestone, partly calcarenite, with *Tetradium* sp.; these beds have many large heads of *T. fibratum* in a quarry north of Oakland School south of Union Furnace	6 0	6 0
Loysburg formation (Field, 1919)		
Clover member (Kay, 1941 *):		
White-weathering, dense, laminated, sublithographic limestone, "chemical lime," with prominent stylolites, to base of good exposure along bluff by railroad	41 0	64 0
Interbedded gray and buff-weathering, laminated limestone—exposed in extreme eastern end of American Lime and Stone Quarry	23 0	23 0
Unnamed member:		
Dark-weathering, dense limestone in interrupted thin, lensing beds with interbedded and penetrating buff-weathering, silty dolomite, colloquially the "tiger stripe" member		

* Type section of the unit.

TABLE II.

SECTION AT BELL MINE, BELLEFONTE, PENNSYLVANIA.

Description of formation	Thickness		Per cent insol. resid.
	Units Ft. In.	To base Ft. In.	
ORDOVICIAN SYSTEM			
MOHAWKIAN SERIES			
TRENTON group			
Salona limestone (Field, 1919):			
Dark, dense, plane-bedded limestone with black shale interbeds, containing several metabentonites, "0" near base			
Nealmont limestone (Kay, 1941):			
Dark, dense, somewhat fossiliferous, thin-bedded limestone, with thicker interbeds, becoming coarser toward top	50	50	8.77*a*
(disconformity)			
BLACK RIVER group			
Curtin limestone (new *)			
Valentine member (Field, 1919):			
Very light gray, white-weathering, dense, heavy-ledged, massive limestone—the "Bellefonte Ledge"	65 9	143 2	1.40
Very light gray, white-weathering, dense, laminated limestone; *Tetradium cellulosum* (Hall) in lower part	25 4	77 5	3.06
Yellow clay—metabentonite "A"	0 3	52 1	.....
Valley View member (new *):			
Light gray, dense, laminated limestone, with argillaceous partings	11 3	51 10	5.62
Dark, medium-textured limestone with argillaceous partings; thin clay—metabentonite "B"—at base; *T. cellulosum* abundant	1 1	40 7	.....
Gray, fine-textured, rather heavy-ledged limestone, somewhat platy near top, with some chert	10 11	39 6	11.52
Prominent parting—metabentonite "C"	0 1	28 7	.....
Gray, fine-textured, rather heavy-ledged limestone; some argillaceous partings; top mud-cracked	15 10	28 6	5.78*b* 5.40
Gray, argillaceous shale, with intercalated limestone; metabentonite "D" at base	1 4	12 8	.....
Dark, medium-textured, heavy-ledged limestone with thin, argillaceous partings; black chert near top; fucoidal	9 8	11 4	12.94
Thin beds of dark limestone with argillaceous interbeds; metabentonite "E" at base	1 8	1 8	.....
Benner limestone (Kay, 1941):			
Stover member (Kay, 1941):			
Dark-gray, fine-textured limestone, heavy-ledged, with wavy partings; *Cryptophragmus antiquatus* Raymond near base	14 7	69 6	5.04
Similar limestone, with few thin limestone conglomerate and crystalline interbeds	54 11	54 11	3.48
Stover member (Kay, 1941):			
Light gray, dense limestone, with beds of limestone-pebble conglomerate; *Tetradium cellulosum* common			

* Type section of the unit; *a*—analysis of comparable bed in base of Nealmont limestone in Chemical Lime Company mine; *b*—analysis of ten feet of beds enclosing metabentonite "C." With the exception noted, the analyses are from Miller, 1934.

46 feet; Benner formation— Snyder and Stover members, 74 and 67 feet; Curtin formation—Valley View member, 48 feet, and Valentine member, exposed for 18 feet. Most of the contacts, and the metabentonite designations, have been painted on the rock for reference.

The terms Carlim, Lemont and "Lowville" have been applied to different units at various localities. The Carlim limestone [8] included the Clover limestone and Hatter formation in the Tyrone district, the overlying Benner and much of the Nealmont being referred to the "Lowville"; in the Bellefonte district,[9] the "Carlim" included beds from the Clover to the lower Valley View, the upper part of that member and the Valentine being classed as "Lowville," and the latter included much of the Nealmont in other sections. The "Lemont member of the Carlim" in the Tyrone district is the Hostler member of the Hatter formation; it is the part of the Valley View limestone between metabentonites E and D at Bellefonte, and a part of the Nealmont at the type locality at Lemont. Confusion developed principally from the misidentification of, and misunderstanding of the ranges of species of *Maclurites, Tetradium* and *Cryptophragmus.*

At present, the principal uses of limestone are for road metal, concrete aggregate, railroad ballast, agricultural lime, and furnace-flux. Chemical composition is of prime importance in the last. In the early years of the century, great quantities were removed for blast-furnace flux, and for this purpose, quarries were opened in the Clover, Eyer and Grazier limestones, separated by a rib of highly siliceous Hostler member from larger openings in the succeeding beds to a hanging wall of Rodman limestone, the uppermost Nealmont. The largest of these were in the Tyrone region, where the higher-grade Curtin limestone is absent. There are inadequate analyses to show the composition of these units. In the American Lime and Stone Company

[8] Butts, Charles: Geologic section of Blair and Huntingdon counties, Central Pennsylvania. Amer. Jour. Sci., 4th ser., 46: 526, 1918. Butts, Charles, Swartz, F. M., and Willard, Bradford: op. cit., p. 18, 1939.

[9] Butts, Charles, and Moore, E. S.: op. cit., p. 32, 1934.

Quarry No. 2 at Union Furnace,[10] a fault repeats the Clover limestone and Hatter formation. 250 feet of beds represented by samples 1 to 6 are in the Benner and Nealmont limestones, having 86 to 93 per cent $CaCO_3$, 2 to 9 per cent $MgCO_3$, and 2.5 to 7 per cent insoluble oxides, principally silica; 45 feet in samples 7 and 8 are in the Hostler member of the Hatter formation, having 65 and 76 per cent $CaCO_3$, 10 and 8 per cent $MgCO_3$, 25 and 16 per cent oxides. More detailed analyses have been published for quarry No. 5 at Blairfour, northeast of Williamsburg;[11] the siliceous Hostler member is evidently represented in ledges 28 to 37, including 57 feet having from 5 to more than 30 per cent silica, iron and alumina; the underlying ledges, about 110 feet, extend from the lower Hatter to below the Clover limestone of the Loysburg, and the overlying 275 feet through the Benner and Nealmont to the Rodman member, represented in the upper 5 feet with 10 to 20 per cent insoluble oxide.

There are no significant thicknesses of relatively pure limestone in these sections that lie south of the area in which the Curtin limestone is preserved. Selected ledges of white-weathering, dense stone in the Clover and Snyder limestones that are quite like the important Valentine limestone at Bellefonte, have been utilized in small operations. The Clover seems to correspond to the commercially important "Mosheim" limestone that is quarried in the Shenandoah Valley from the Potomac north of Martinsburg, West Virginia, to the vicinity of Strasburg, Virginia; the rock is considerably more pure than the Clover of Central Pennsylvania. Ledges in the Snyder limestone are burned in kilns at Waterside and Ashcom, east of Orbisonia in the Blacklog Valley, and southeast of Spring Run in the Path Valley; the whole of the Snyder, reduced to 20 feet, is relatively pure at the last locality.

The Valentine limestone member of the Curtin formation, present only in parts of Centre and Clinton counties, is the im-

[10] Miller, B. L.: Limestones of Pennsylvania. Penna. Geol. Surv., 4th ser., Bull. M20: 413, 1934.

[11] Miller, B. L.: ibid., p. 233–234, 1934.

portant source of high-grade limestone. Inasmuch as the stratigraphic relations limit its distribution, they will be discussed more fully than of the other units.

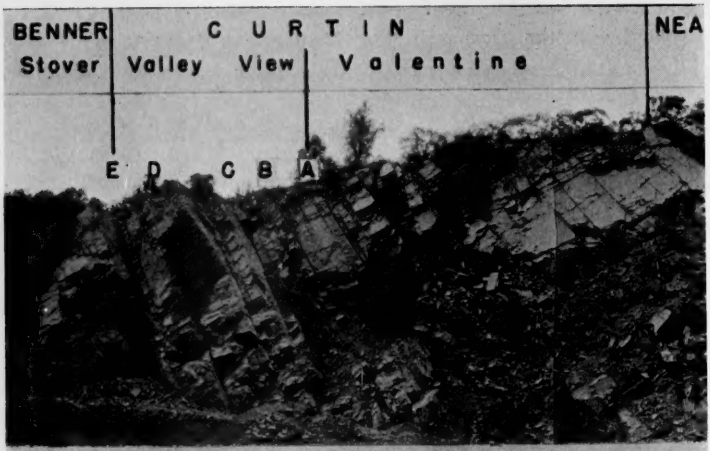
THE VALENTINE MEMBER OF THE CURTIN FORMATION.

The Chemical Lime of the Bellefonte District.

The Curtin limestone (new, Curtin Gap, three miles northeast of Bellefonte, Centre County) is typically exposed in the quarry wall south of the headframe of Bell Mine, just west of Bellefonte (Table II and Fig. 3). It is separable into two members, the lower, Valley View, comprising 52 feet of impure limestone from the base of metabentonite "E" to that of metabentonite "A," and the upper, Valentine, having 90 feet of high-grade limestone extending to the unconformity at the base of the Nealmont limestone. The term "Bellefonte Ledge" is applied colloquially to the upper 65 feet of the Valentine member at this locality; it is not a stratigraphic term, for the footwall in several quarries and mines differs somewhat in horizon, and "chemical lime" at other localities in other units has been called "Bellefonte lime." The Bellefonte dolomite (Ulrich,1911) is much older, being lower Ordovician in at least its lower part; the Bellefonte sandstone is in the middle of the dolomite,[12] and though the overlying beds have been classified as Bellefonte in the Bellefonte district, they correspond to the most of the Loysburg formation that has been considered to be Chazyan farther south. The Curtin formation is exposed only in parts of Centre, Clinton and Lycoming counties. The limestone thins from 100 to 150 feet along the northwest side of the Nittany Valley to extinction along a line from Tyrone to north of Lemont, Oak Hall, and Spring Mills and south of Millheim (Fig. 5).

The Valley View member (new, from a hamlet 2 miles southwest of the type section at Bell Mine) is remarkably constant in character and thickness from the Nippenose Valley, south of Jersey Shore, to Pleasant Gap and the western end of the Belle-

[12] Butts, Charles, and Moore, E. S.: op. cit., p. 32, 1934.



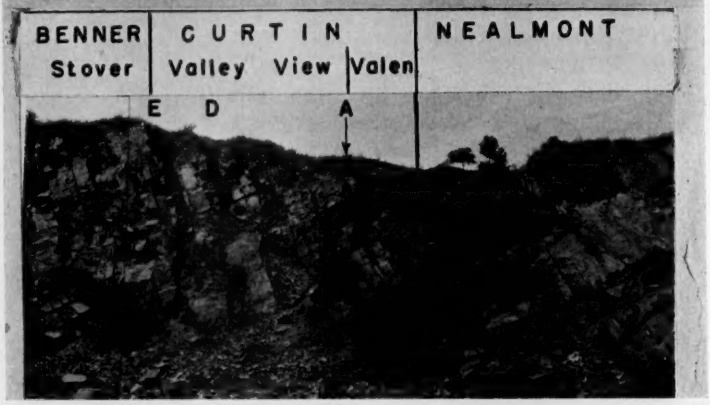
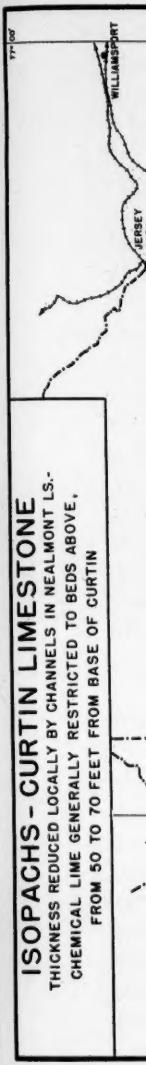


FIG. 3 (Upper). Section west of headframe of Bell Mine, Bellefonte.
FIG. 4 (Lower). West end of Quarry 15½, one mile east of Bell Mine, showing diminished Valentine limestone.


WILLIAMSPORT
JERSEY
ISOPACHS - CURTIN LIMESTONE
THICKNESS REDUCED LOCALLY BY CHANNELS IN NEALMONT LS.-
CHEMICAL LIME GENERALLY RESTRICTED TO BEDS ABOVE,
FROM 50 TO 70 FEET FROM BASE OF CURTIN

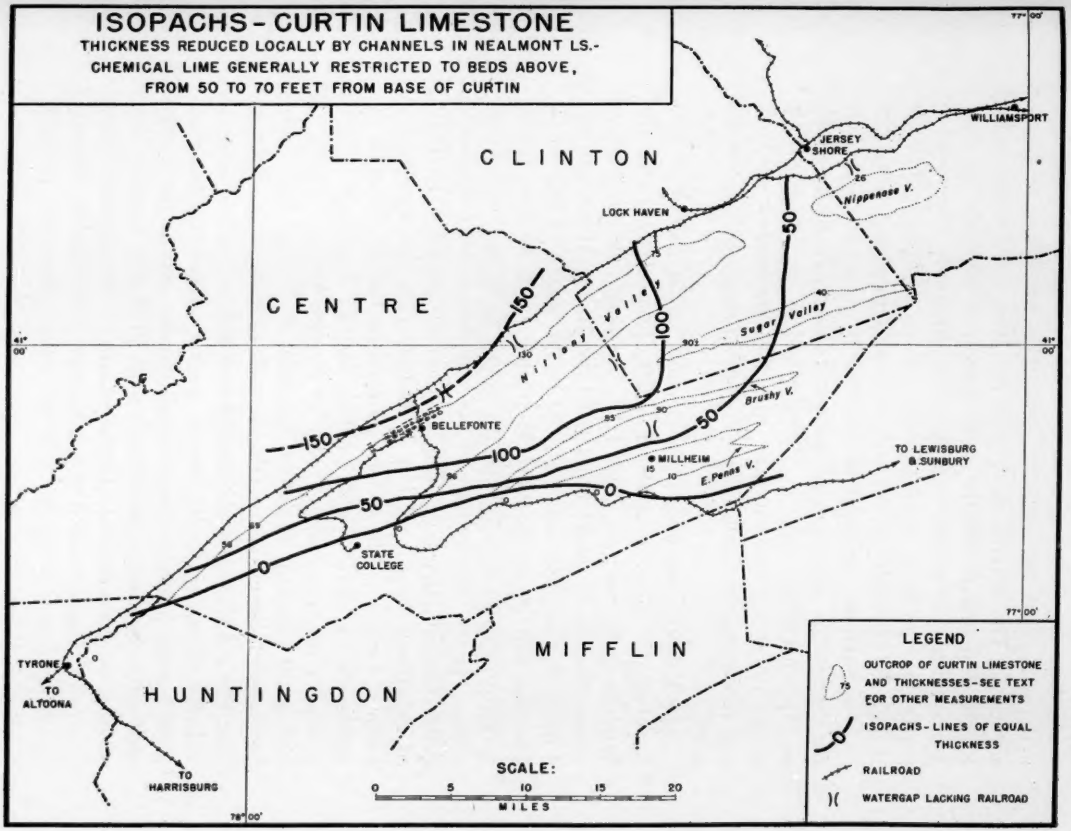


FIG. 5. Map showing distribution of thickness of the Curtin limestone; an isopachal map.

fonte district. Fifty-two feet at the type section (Table II), it thickens to 65 feet at Salona, and thins to 43 feet at Pleasant Gap. The several metabentonites form exceptional units for the demonstration of the small changes in thickness, for they are synchronous altered volcanic ash deposits. The member persists to the limit of distribution of the Curtin formation; though it is bevelled by the unconformably overlying Nealmont near the limit, the original extent may not have been much greater, for the beds are more conglomeratic and calcarenitic than normal, as exposed in the quarry in Millheim and by the bridge a mile south, where the disconformity with the Nealmont is obvious, and in the quarry south of Grays Church, northeast of Stormstown.

The Valentine member, from a "small hamlet and forge near Bellefonte,"[13] is of exceptional purity, particularly above the basal 15 to 25 feet; see Table III. The maximum thickness is rather constant in the 15 miles from the Martin Miller Quarry, 4 miles west of Bellefonte (Fig. 6) to the quarry of Whiterock Quarries east of Jacksonville, increasing from 75 feet at the former to 90 feet at Bell Mine, decreasing to 80 feet at Jacksonville. The unit diminishes to 10 feet at Salona and is absent at Antes Gap in Nippenose Valley, 20 miles beyond. Southeast of Bellefonte, there is 52 feet at Pleasant Gap, but none to the south at Lemont. The member is exposed for 40 feet west of Tylersville in Sugar Valley, absent east of Loganton, where Nealmont overlies Valley View. In Brushy Valley, 80 feet of high-grade limestone underlies Nealmont at Spring Bank, subjacent beds being unexposed; the member is missing at Millheim in East Penns Valley, and to the south and east.

In the Bellefonte district, there is general constancy, but marked local decrease. Eighty feet thick in the east end of the quarry west of the road north of Coleville (No. 21M, Fig. 6), it is only 48 feet in the west end, 1500 feet away; the Nealmont cuts gradually down, the bed overlying the Valentine in the east becoming separated by 35 feet of impure limestone partially

[13] Field, R. M.: op. cit., p. 414, 1919.

TABLE III.

CHEMICAL ANALYSES OF VALENTINE LIMESTONE.

No.	Stratigraphic unit and locality	No. samples	Thickness; feet	$CaCO_3$	$MgCO_3$	SiO_2	Al_2O_3 and Fe_2O_3	Insoluble in acid
	Upper VALENTINE; "Bellefonte Ledge":							
1	Bell Mine	58	65	97.40%	1.00%	1.00%	0.40%	1.40%
2	Chemical Lime Mine No. 1	81	55	....	....	0.64	....	0.91
3	Martin Miller Quarry	31	62	....	....	....	....	1.50
4	Whiterock Quarry No. 1	6	30	....	....	0.59	....	....
	Lower VALENTINE:							
5	Bell Mine	2	25	95.50	1.50	2.00	1.05	3.05
6	Chemical Lime Mine No. 1	30	22	....	....	2.02	....	2.59
7	Martin Miller Quarry	7	15	....	....	....	....	3.05
8	Whiterock Quarry No. 1	4	15	....	....	2.43	....	....
	VALLEY VIEW:							
9	Bell Mine	1	10	92.50	1.90	5.00	0.62	5.62
10	Bell Mine	5	50	88.10	2.00	7.70	1.00	8.70
11	Martin Miller Quarry	8	15	....	....	....	....	7.52
12	Whiterock Quarry No. 1	1	10	....	....	4.20	....	....

Analyses are of suites of samples from successive beds; nos. 5, 9, 10 and 12 may be averages of several analyses; no. 10 includes no. 9.

Bell Mine, American Lime and Stone Company, Bellefonte; analyses from Miller, op. cit., p. 286, 1934; listed insoluble residue is total of silica, alumina and iron oxides.

Chemical Lime Company Mine No. 1 of the National Gypsum Company, Coleville; analyses from Bayard Magee, manager.

Martin Miller Quarry; analyses from Bayard Magee, National Gypsum Company.

Whiterock Quarry No. 1, Pleasant Gap; analyses by C. J. Lewis, through R. C. Noll, president, Whiterock Quarries; nos. 4 and 8 successive in quarry face, not extending to top of Valentine limestone, no. 12 of uppermost Valley View.

coarse, calcite-sandstone or calcarenite. The "Bellefonte Ledge" so thins in the mine below that it has not been removed for 2000 feet along the strike. More extreme thinning is shown in the quarry west of the Pennsylvania Central Railroad (No. 15½), the Valentine being but 17 feet thick, overlain by 32 feet of coarse calcite sandstone of the basal Nealmont, with disconformity of as much as 4 feet in the western corner of the opening (Fig. 4). The quarries to the west (No. 17) and east (Nos. 15 and 13) have about 80 feet of Valentine.

FIG. 6. Sections of Curtin limestone, showing succeeding regional unconformity and local disconformity.

Thus, the Nealmont limestone bevels the Valentine regionally, and fills channels within it locally. There seems no way of anticipating the presence of channels other than through examining surface exposures, and drilling. If the quarry exposures and mines are representative, the "Bellefonte Ledge" is so thinned as to be unminable in about 10 per cent of the outcrop. The mine of the American Lime and Stone Company north of Coleville suggests that the channel there has a northwestward trend, and thus down the dip. In areas where the Valentine is concealed, its outcrop can be located on the surface by identification of exposures of other members in the sequence, and consideration of structure. Faults are responsible for offset and cutting-out of the member in several places; the fault north of Bellefonte offsets the outcrop about one-fourth mile, and minor thrust faults have been encountered in the mines west of the town.

There are local impure beds within the Valentine that represent areas of concentration of impurities in the original deposition. In analyses of the "Bellefonte Ledge" at Bell Mine,[14] the per cent of silica, alumina and iron oxide reaches a maximum of 1.60, and that of $CaCO_3$, a minimum of 97.32 in single samples from one foot intervals. In the Chemical Lime Company Mine analyses (Table III), insoluble residue totals 4.41 per cent in one sample from two-thirds foot; four samples from 3 feet exceed 2 per cent in the thickness of 55 feet of high-grade limestone.

In summary, the Valentine limestone is the source of the "chemical lime" that is mined and quarried in the Bellefonte region. The distribution of the member is controlled by an unconformity that succeeds, gradually bevelling it to extinction southeastward, and locally having channels that reduce the thickness of best stone, or cut it out.

COLUMBIA UNIVERSITY,
NEW YORK CITY,
December 17, 1942.

[14] Miller, B. L.: op. cit., p. 287.

GOLD ORES OF THE LITTLE LONG LAC AREA, ONTARIO.

H. S. ARMSTRONG.

ABSTRACT.

In the Little Long Lac Area gold occurs in two main types of orebodies. The first, exemplified by the Number 2 and Number 30 vein systems at Hard Rock, and the North and West ore zones at MacLeod-Cockshutt, consists of massive sulphide replacement bodies in iron formation. The second consists of silicified zones associated with intrusive acid porphyries, found in the South ore zone at MacLeod-Cockshutt, and in the orebodies at Magnet Consolidated, Bankfield, Tombill, and Jellicoe. Gold-quartz veins associated with acid porphyries, a variety of the second type, are found in the Number 1 vein system at Hard Rock, and the 210 quartz vein at MacLeod-Cockshutt. The orebodies at the Little Long Lac mine are confined to shear zones in arkose, and do not conform to the above general classification.

Hand specimens and polished sections typical of these orebodies have been studied. Composite diagrams representing the mineral paragenesis in each orebody or mine have been drawn up and are discussed in this paper. These eleven diagrams are combined in a table representing a generalization of the mineral relations over the entire area. In addition, the sequence of mineralization is presented in terms of radicles.

From the evidence of mineral sequences, and certain other investigations, it is apparent that the ore deposits of the Little Long Lac area may be correctly placed in Lindgren's upper hypothermal, or lower mesothermal, zone. Possible sources of the ore-depositing solutions are discussed, but no final statement made.

INTRODUCTION.

Location.

THE Little Long Lac area is about 75 miles north of Lake Superior in the Port Arthur mining division of the District of Thunder Bay, Ontario. The area comprises six townships: Houck, McQuesten and Fulford to the north, and Ashmore, Errington and Lindsley to the south of the Port Arthur-Longlac branch of the Canadian National Railway. The seven mines dis-

cussed are distributed through Errington, the western part of Ashmore, and the eastern part of Lindsley townships.

The town of Geraldton, on the railroad, 21 miles west of Longlac, is a convenient base for operations. Transportation by aeroplane is available. During the summer of 1940, the highway connecting Port Arthur and Geraldton was opened to traffic.

The history of the development of the area has been recorded by E. L. Bruce.[1] The first mine in operation in the region was the Little Long Lac mine, which began production in November, 1934.

General Geography.

Geraldton is at an altitude of 1,110 feet above sea level. The relief is typical of the Canadian Shield: prominent hills or rock ridges are rare and swamps and small lakes are numerous. There are a few larger lakes, but they are relatively shallow. The drainage of this area is sluggish, owing to the proximity of the height of land. Little Long Lac (Kenogamisis lake) drains northeast to James Bay by way of the Kenogami river.

Well-developed esker ridges and other glacial deposits are conspicuous not only from the air, but in aerial photographs as well. The general trend of the ridges is northeast-southwest, but this is by no means constant. As a result of the deposition of a thick mantle of glacial debris, rock outcrops are neither abundant nor extensive.

The marshy areas are characteristically spruce, tamarac, and cedar muskegs, with some cedar and alder swamps. Drier sections have a forest cover of spruce and jackpine, or of poplar and birch. In recent years, forest fires have cut swaths through the region and destroyed much timber which would have been of value in the early stages of mine and prospect development.

Steam was originally the source of power for the early development of the mines in the area. Electrical power is now available from the Nipigon river, 100 miles distant.

[1] Bruce, E. L.: Little Long Lac Gold Area. Ont. Dept. Mines, 44, pt. 3: 3–5, 1935.

GENERAL GEOLOGY.

Stratigraphy.

The stratigraphy of the Little Long Lac area has been outlined by Bruce.[2] The following discussion is taken from his report, supplemented by personal observations made during the summer of 1940. The table given here is a modification of that of Doctor Bruce.

QUATERNARY	
Recent:	Clay, peat.
Pleistocene:	Till, sand, gravel.
	Unconformity
PRECAMBRIAN	
	Quartz diabase dikes.
	Intrusive contact
Later Precambrian:	Granite porphyry, feldspar and quartz porhpyry dikes.
	Intrusive contact
	Diorite, diorite porphyry.
	Intrusive contact
"Timiskaming-type":	Greywacke, arkose, impure quartzite, chlorite schists.
	Iron formation.
	Conglomerate.
	Unconformity
"Keewatin-type":	Greenstone, volcanic fragmentals, chlorite schists, and thin beds of black slate.

"Keewatin-type." Basic volcanics, generally andesitic in composition, constitute most of this series. Subordinate to the lavas

[2] Ibid., pp. 10–27.

are a few lenses of agglomeratic and tuffaceous rock, and some narrow bands of black slate. Weathering of the andesites shows that they are ellipsoidal or pillow lavas. Other varieties of this rock, in some places coarse-grained, include amygdaloidal and massive greenstones, the latter often associated with ellipsoidal lavas. The coarse grain of the massive greenstones may well cause them to be mistaken for diorite, with which they are identical in chemical and mineralogical composition. Chlorite schists commonly result from the operation of shearing stresses on the basic volcanics.

Observations taken in order to determine the attitude of the volcanics are inconclusive, the outcrops being too widely spaced. The strike of the schistosity is nearly east-west, the dip almost vertical.

"Timiskaming-type." Most of the rocks of this series are extremely varied clastic sediments. Although no definitely basal conglomerate has yet been uncovered, a somewhat continuous conglomeratic member has been found close to the Keewatin greenstone. Most of the conglomeratic beds are lenticular and discontinuous. Pebbles of granite, feldspar porphyry, quartz, chert, and a fine-grained greenstone-like rock have been found in matrices varying from slaty and schistose chloritic to massive fine-grained and quartzose material. No fabric analyses have yet been made on the pebbles although their spherical to ellipsodial shapes would lend themselves to such investigations. A careful search was made for conglomerate boulders in these conglomerates, but none was found.

Commonest of the rocks of the Timiskaming type are gray, in some places greenish, greywackes of which quartz is the most prominent constituent. As the proportion of feldspar, usually oligoclase, increases, the rocks may better be termed arkosic greywackes or arkoses. Among the commoner accessory minerals, variable in quantity, are amphibole, calcite, chlorite, and magnetite. The east-west shearing in the area has in many places obscured the bedding of these fine-grained sediments. Gradations in grain size, however, are well developed in some places, where

observations have indicated that the tops of the beds are toward the south.

Quantitatively less important than the greywackes, but of considerable interest to students of ore deposits, are the beds of iron formation on which Brant [3] made geophysical surveys during the summer of 1939. The extensive outcrops at one locality illustrate the well-banded character: layers of magnetite, hematite, and quartz alternate with bands of red or white fine-grained silica. The richest iron formation bands contain less than 40 per cent of iron, and therefore, at the present time, are not considered to be iron ore. The origin of the iron formation remains an open question.

Fine-grained chlorite schists are interbedded with clastic sediments in some places. Bruce [4] has examined thin sections of some of these and has interpreted one type as a dike or sill of diorite. He discounts the theory that some of the beds are tuffaceous, and explains the high chlorite content on the basis of a considerable proportion of ferrous iron in the original rock. The recrystallization of such a rock would result in the formation of chlorite.

Later Precambrian. The earlier Precambrian greenstones and sediments have been cut by intrusive rocks of at least three ages.

(i) Diorite and Diorite Porphyry. These dark-colored or speckled rocks form irregular or oval-shaped masses and elongated sill-like lenses. Two large areas, possibly irregular stocks, as well as numerous smaller areas and sills occur in the region. The rock of the stock-like masses has a granitic texture. The variable color of the rock types is a result of considerable variation in the proportion of light to dark minerals. Andesine is the most abundant mineral, even in the darker varieties; the remainder of the rock is made up of dark-green to black amphiboles, quartz, calcite, and chlorite.

Massive diorite is difficult to distinguish from the coarse-

[3] Brant, A.: A geophysical and geological survey of the Little Long Lac Area. Ont. Dept. Mines, Prelim. Rep., May, 1940.

[4] Bruce, E. L.: Op. cit., pp. 15–16.

grained lavas. The discrimination between volcanic or sedimentary chlorite schists and intensely sheared fine-grained diorites which have become chlorite schists is also uncertain.

(ii) Acidic Intrusives. Two types of soda-rich intrusives occur in the area. A soda-granite porphyry mass of unknown shape contains abundant albite and considerable quartz; the remainder comprises orthoclase, apatite, and the secondary minerals calcite, chlorite, epidote, and sericite.

Many small masses and dikes of feldspar and quartz porphyry constitute the second type. Albite is the common phenocryst mineral, but the dike rocks are marked by abundant orthoclase and less quartz than the soda-granite porphyry. Quartz, calcite, sericite, and chlorite are the chief constituents of the ground mass.

The general trend of the dikes, which are themselves sheared, is parallel to the general strike of the country. The dikes cut all the rocks previously mentioned, and although presumably not all precisely contemporaneous, analyses [5] suggest that they probably came from a common magmatic source.

(iii) Quartz Diabase. Quartz diabase dikes, usually less than 120 feet wide, are common throughout the area wherever they are not covered by overburden. The general trend of these vertical dikes is north-south. Labradorite and augite crystallize in characteristic ophitic texture; quartz, magnetite and hornblende are primary accessory minerals, chlorite and epidote are secondary.

These dikes are classed as Keweenawan in age by analogy with similar rocks throughout Northern Ontario, particularly those near Lake Nipigon, about 50 miles to the west.

Pleistocene. Unconsolidated gravels, sands, and clays lie unconformably upon the Precambrian rocks. Bruce [6] notes the presence of probably pre-Pleistocene weathered zones in some of the prospects. In some places as much as 60 feet of sand and gravel have been found forming irregular knolls and ridges or elongated eskerine deposits. No varved clays have been found in the region.

[5] Ibid., pp. 21–22.
[6] Ibid., p. 25.

Recent. Peat and moss deposits are accumulating in the lakes, marshes, and swamps of the present time. Some of the peat deposits have attained notable thicknesses.

Structure.

The structural relations of the volcanic and sedimentary series have been largely obscured by the heavy drift overburden. The direction of strike and amount of dip may be determined from the conglomerate lenses and bands of iron formation, but in the greywackes extreme care must be exercised to distinguish between bedding and shearing. Flat dips to the north or south have been noted, but in general the beds are nearly vertical.

The somewhat continuous band of conglomerate, which has been mentioned previously as outcropping close to the Keewatin greenstone, contains some pebbles which have been derived from the lavas. The sediments are, therefore, younger than the greenstone, and because they lie to the south, the structure may be interpreted as synclinal. This inference is supported by the relations between bedding, schistosity, and the plunge of folds in the iron formation.

Despite the scattered nature of the outcrops, the sediments have proved to be the most amenable to structural investigations. Bruce [7] has shown that the southern limb of the syncline probably lies well to the south of Little Long Lac, possibly displaced by the granites which are found in that direction. He has traced a gradation southward from the basal conglomerate through a zone of heterogeneous sediments into a wide zone of slaty greywackes.

The gold mines discussed in this paper thus lie within a major syncline which has a westward plunge of about 30°. Steeply dipping, closely folded minor structures complicate the general synclinal structure.

The recognition of faulting is made difficult by the scarcity of outcrops and by the discontinuous character of key members. Strike faulting has probably occurred as evidenced by the strongly developed east-west shear planes. Low angle faults have been

[7] Ibid., p. 17.

met with in underground developments. In other regions the displacements of diabase dikes serve as a useful indicator of faulting, but here there seems to be little displacement, at least at the surface.

THE ORE DEPOSITS.

The geology and orebodies are described from data available in published reports as well as from information supplied personally by officials of the various mines. The descriptions of the ores are based on the results of examination by the writer of hand specimens and polished sections. The diagrammatic representations of the mineral paragenesis at each mine are composite diagrams compiled from similar tables for individual polished sections and hand specimens. As a general rule, no single specimen will present the complete sequence of any one composite table.

In the following descriptions, the term *bleb* is used in a sense which differs to some extent from the dictionary definition. The definition implies small bubble-shaped or drop-shaped masses. The writer uses the term to signify any very small anhedral mass within another, regardless of whether it be angular or rounded. The term, however, does not include minute regular crystal inclusions such as are found in some sections.

Hard Rock Gold Mines, Limited.

General Geology. The ore deposits at the Hard Rock mine are associated with sediments, porphyry masses, and diabase dikes.

The sediments are greywackes, generally fine-grained and rather dark grey in color. Bedding may be distinct, but in places it is obscured by shearing to such an extent that the rock is more properly termed slate or slaty greywacke. Commonly interbedded with the greywacke are bands of hematite, magnetite, and jasper varying in width from one to six inches and separated by as much as five feet of greywacke. All gradations from this very "light iron formation" to finely laminated "heavy iron formation" are to be observed. The latter consists of bands of greywacke or quartz alternating with magnetite and hematite or jasper. Diamond drill intersections indicate lenses of conglomerate in the

greywacke, in some places exceeding 100 feet in thickness. Close folding and fracturing of these members have resulted in a highly contorted sedimentary series.

Two types of porphyry, both later than the sediments, outcrop on the property and also have been encountered in the underground workings. The basic type outcrops as diorite porphyry and chlorite schist. The difficulty of distinguishing between the latter and volcanic material has been discussed. The larger area of diorite porphyry is probably an irregular boss.

Near the western side of the Hard Rock group of claims, and extending several hundred feet on to the eastern part of the adjacent MacLeod-Cockshutt group, is an irregularly elliptical mass of albitite porphyry. At one time covered with drift and swamp, the mass has been uncovered and now rises as a low hill of light-weathering, pale gray, massive rock cut by veinlets of quartz. The porphyry body is a pipe-like intrusion plunging to the westward at an angle of 30°. Underground development has shown tongues of porphyry extending from both ends of the pipe along bedding and shear planes in the greywacke. The margins have a banded structure as a result of the *lit par lit* mode of emplacement of the porphyry.

Diabase dikes are not numerous. The albitite porphyry pipe is cut by two narrow sub-parallel dikes trending east of north. Similar narrow dikes which do not outcrop have been encountered underground. None of these dikes bears any genetic relation to the ore deposits.

The Orebodies. The orebodies at the Hard Rock mine very closely resemble those at the adjacent MacLeod-Cockshutt with which they are continuous. Three different ore types have been developed, namely, the Number 1, Number 2 and Number 30 vein systems.

The Number 1 system comprises free gold-bearing quartz veins within the albitite porphyry. These veins closely resemble the 210 Quartz Vein at MacLeod-Cockshutt insofar as structural relations are concerned. Certain differences in mineralogy are evident in the high pyrite content of most of the Hard Rock veins.

Only where the quartz is extremely fine is gold found in visible quantities. The veins of this system are not being worked at the present time and no specimens were available.

The Number 2 system differs somewhat from the South Ore Zone at MacLeod-Cockshutt. At both mines the ore is associated with the main albitite porphyry pipe. The difference lies in the fact that at MacLeod-Cockshutt the second associated rock is greywacke, while at Hard Rock it is iron formation. The Number 2 vein system comprises beautifully banded ore, alternate layers of closely folded iron formation having been replaced by sulphides. This banded ore is cut transversely by quartz-tourmaline veinlets which represent fracture fillings with some replacement. No production is being maintained from this system at the present time.

The Number 30 system, or North orebody, is the eastward extension of MacLeod-Cockshutt's North Ore Zone. Like that ore, the Hard Rock ore from this system is a massive sulphide replacement of greywacke bands in iron formation. The structure of the Hard Rock system, however, is not so highly irregular as that of the MacLeod-Cockshutt ore zone. A single vertically-standing large drag-fold apparently relieved the folding stresses which gave rise to the highly complex and irregular structures to the west. The massive sulphide ore is fairly constant across the section of the fold, as also along its western arm. Developed over a stoping length of 850 feet, this orebody produced 97,568 tons of ore, averaging $8.56 per ton, during the nine months ending September 30, 1941.

Mineral paragenesis (Figs. 1, 2, 3, 7, 11). The mineralogy of the Hard Rock ores is rather simple. Twelve metallic minerals were identified, of which pyrite and arsenopyrite are the most abundant. Free gold was observed in more than half the polished sections examined, but it is not visible in the hand specimens, and none was "high grade."

The following composite tables of paragenesis are compiled for the two main orebodies, the Number 2, and the Number 30 vein systems:

TABLE 1.

NUMBER 2 VEIN SYSTEM.

TABLE 2.

NUMBER 30 VEIN SYSTEM.

Discussion of the Tables. Table 1. The absence of arsenopyrite is a noteworthy feature of these ores. Although arsenopyrite was not observed in hand specimens or polished sections, it seems very likely that additional sections would reveal its presence, since in this general area arsenopyrite, like pyrite, is almost ubiquitous. Pyrite was the first mineral to crystallize; in the sections available it forms large masses which were cracked during the period of fracturing that followed. The cracks in the pyrite were filled with quartz which carries pyrite conforming

to the quartz. Some pyrite in the sections is conformable to quartz, indicating that where no fracturing has taken place, there is an overlap in the relationship between quartz and pyrite.

The gray mineral identified as ilmenite conforms to and in some places replaces pyrite and quartz. Its relation to the minor sulphides is not clear; smooth and irregular boundaries were observed but no crystal faces of the minor sulphides were found. Ilmenite likely occupies the position indicated in the diagram.

Pyrrhotite, sphalerite and chalcopyrite occur as minute rounded and irregular blebs, occasionally following fractures, in the earlier pyrite grains (Fig. 11). Pyrrhotite and sphalerite have mutual boundaries which have served, in some places, as channels for the infiltration of chalcopyrite which replaces them. In other places chalcopyrite seems to be contemporaneous with sphalerite and pyrrhotite. Cubanite was seen in a single bleb associated with chalcopyrite. Calcite conforms to all the minerals appearing above it in the diagram.

A second period of fracturing is indicated by the presence in one polished section of a vein of quartz and calcite which carries minute euhedra of pyrite. This may be regarded as a third age of pyrite. Black acicular crystals in the quartz veins of the hand specimens are needles of tourmaline which crystallized in part before the quartz but probably later than the pyrite. The fact that some of them conform to crystal outlines of quartz is suggestive of an overlap in the sequence of deposition. A second generation of calcite which occurs in the veinlets is prevailingly later than the second quartz, but in some places mutual boundaries of the two minerals indicate overlap.

The exact position of gold in the sequence is uncertain. It probably was introduced by the quartz-tourmaline vein solutions, but the possibility that it came in with the earlier quartz and minor sulphides should not be overlooked. Gold occurs as irregular blebs in the early pyrite where it fills spaces between the closely set pyrite crystals. It is also found along the contacts of pyrite with the minor sulphides, these contacts apparently having afforded easy access of the gold-bearing solutions.

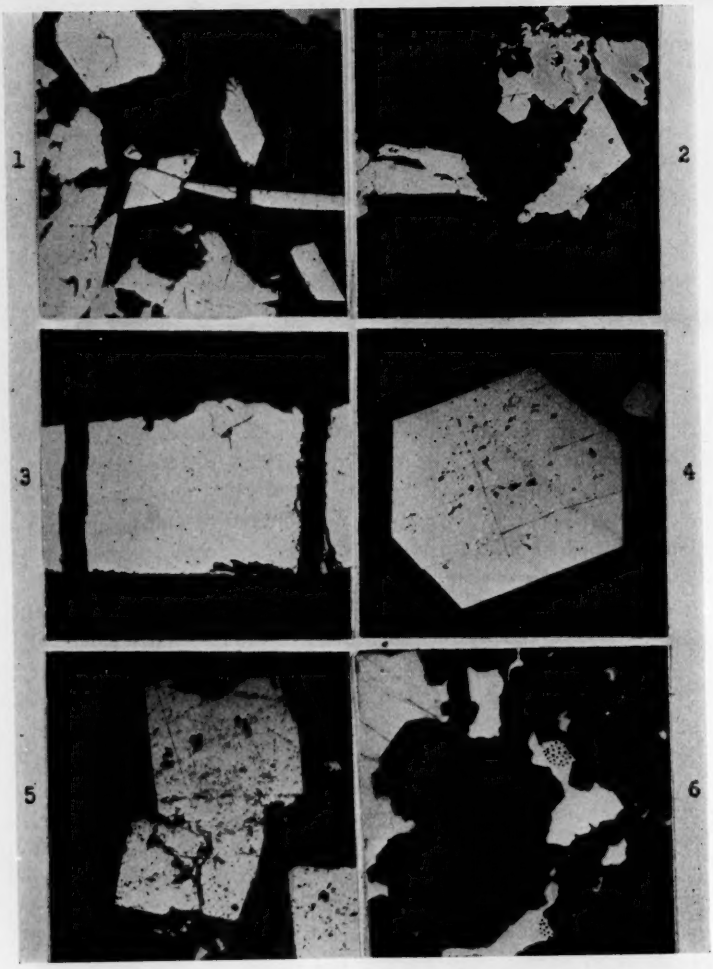


FIG. 1. Diamond- and lath-shaped euhedra of arsenopyrite. Hard Rock Gold Mines, Limited. Arsenopyrite (white), quartz and calcite (black and gray). × 50.

FIG. 2. Skeletal crystals of arsenopyrite. Hard Rock Gold Mines,

During a late period of movement, the quartz-tourmaline veins have been locally faulted and slickensides developed.

Table 2. Arsenopyrite occurs as large well-developed crystals with euhedral outlines (Fig. 1) and as skeletal crystals (Fig. 2). Many of these crystals have been broken across (Fig. 3), the fractures being filled with quartz and metallics. Unfractured pyrite conforms to arsenopyrite but is, in part, automorphic against quartz. A considerable overlap between pyrite and quartz is indicated by the fact that much of the pyrite conforms to quartz crystal outlines. In several of the sections a period of shearing is suggested by the parallel alignment of flakes of graphite and the rounding of pyrite masses, and quartz may have been introduced or recrystallized during this shearing. The overlap relationship of pyrrhotite and quartz was seen in some sections where quartz conforms to pyrrhotite outlines. The deposition of pyrrhotite continued past that of sphalerite, resulting in the overlap relationship shown in Table 2. Galena and sphalerite have mutual boundaries in some sections, but for the most part galena conforms to sphalerite and has mutual boundaries with some of the pyrrhotite. Chalcopyrite in places conforms to galena and pyrrhotite, but was elsewhere observed to have mutual boundaries with these

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Limited. Arsenopyrite (white and somewhat mottled—the mottled appearance is due to reflection pleochroism), quartz (black), calcite (dark gray). × 50.

FIG. 3. Arsenopyrite lath fractured transversely. Hard Rock Gold Mines, Limited. Arsenopyrite (white—note the matching walls in the fractures), pyrite (light gray), quartz and calcite (dark gray). × 50.

FIG. 4. Automorphic replacement of argillite by pyrite. Bankfield Consolidated Mines Limited. Pyrite (light gray—note the manner in which the "grain" of the rock is transected), non-metallics (black). × 50.

FIG. 5. Euhedron of pyrite fractured and displaced. Tombill Gold Mines Limited. Pyrite (light gray—note the manner in which the larger part has broken the smaller), quartz (black), calcite (dark gray). × 50.

FIG. 6. Galena with euhedral gold. Magnet Consolidated Mines Limited. Galena (white), gold (grayish, scratched—note the euhedral grains, stippled, surrounded by galena in the middle of the figure), quartz (dark gray). × 110.

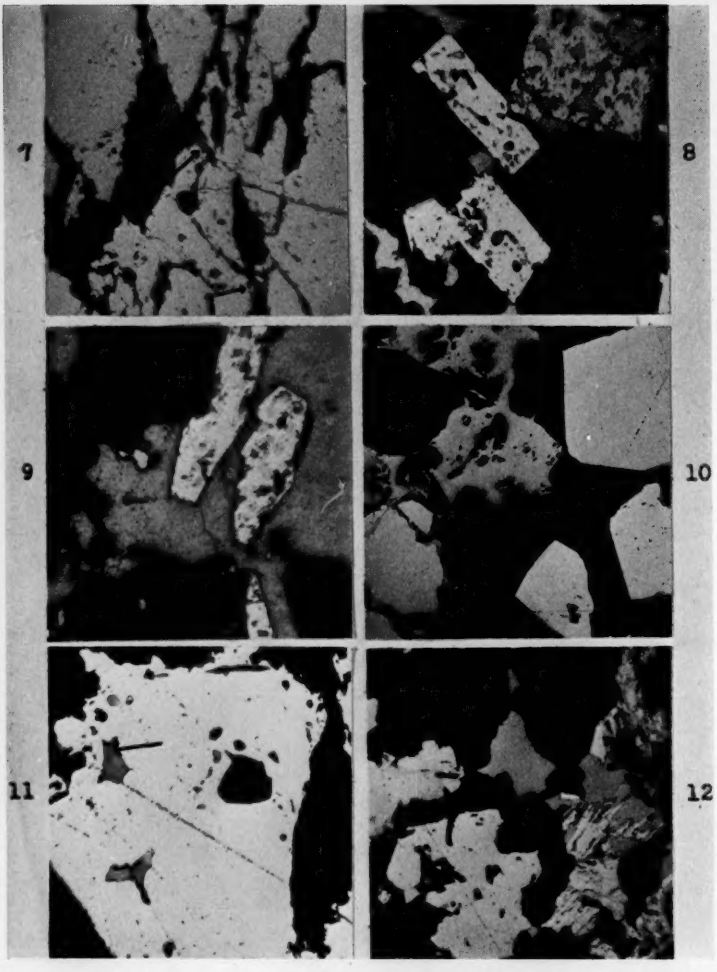


FIG. 7. Gold with quartz in fractured arsenopyrite. Hard Rock Gold Mines, Limited. Arsenopyrite (white), quartz (dark gray), magnetite (light gray), gold (indicated by arrows). ×110.

FIG. 8. Gold associated with pyrite and quartz. Bankfield Consolidated

two minerals. The gray mineral identified as ilmenite(?) is later than chalcopyrite, in some places replacing it, in others conforming to the outlines of the minerals which precede it in the table. Minute crystals of a mineral identified as leucopyrite are associated with pyrite and conform to its outlines. Although not observed in association with ilmenite, the position noted for it in the table is probably correct.

During the second period of fracturing, which followed the deposition of leucopyrite, all the former minerals were broken transversely. Minute euhedra of arsenopyrite are embedded in the quartz-calcite filling of the interstices. Calcite conforms to the later arsenopyrite but preserves its outlines against quartz with only a slight overlap in the sequence. A second age of pyrite occurs as small grains which are in overlap relationship with quartz. Most of the pyrite conforms to quartz, but some is automorphic against it. Pyrrhotite was found alternating with pyrite in a veinlet in one of the hand specimens. The position of gold is difficult to ascertain definitely (Fig. 7). It was probably brought in along with these later solutions and deposited last. The late calcite shown in the table represents calcite, possibly of supergene origin, which has crystallized in vugs.

Mines Limited. Gold (light gray), pyrite (white), quartz (black). × 110.

FIG. 9. Gold associated with arsenopyrite and quartz. Tombill Gold Mines Limited. Gold (light gray), arsenopyrite (white), quartz (black). × 110.

FIG. 10. Pyrite with quartz and chalcopyrite. Tombill Gold Mines Limited. Pyrite (white), quartz (black), chalcopyrite (light gray). × 50.

FIG. 11. Inclusions of chalcopyrite and pyrrhotite in pyrite. Hard Rock Gold Mines, Limited. Pyrite (white), pyrrhotite (dark gray), chalcopyrite (light gray—lath of cubanite indicated by arrow), quartz (black). × 110.

FIG. 12. Intergrowth of pyrrhotite and leucopyrite. Magnet Consolidated Mines Limited. Pyrrhotite (medium gray), leucopyrite (light gray, dendritic mineral), pyrite (white), quartz (black). × 110.

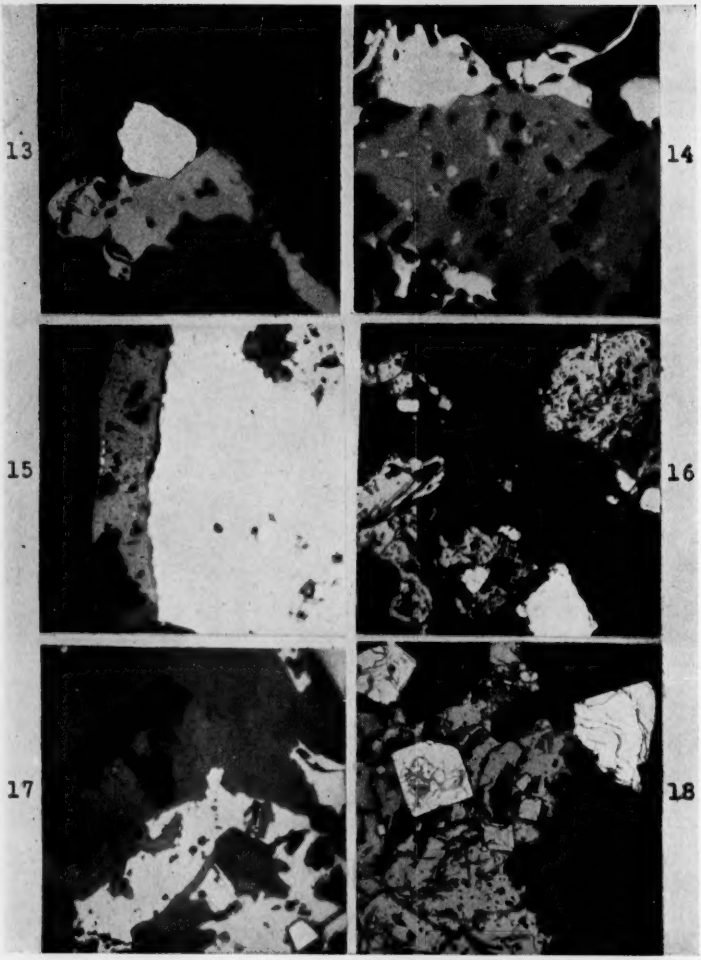


FIG. 13. Pyrite, pyrrhotite, and chalcopyrite. Magnet Consolidated Mines Limited. Pyrite (white), pyrrhotite (medium gray), chalcopyrite (light gray), quartz (black). × 110.

FIG. 14. Chalcopyrite and sphalerite. Tombill Gold Mines Limited.

MacLeod-Cockshutt Gold Mines Limited.

General Geology. The rocks in the MacLeod-Cockshutt group of claims are identical with those in the adjacent Hard Rock group, but the types of rock which outcrop afford a few points of difference. At the western boundary of the group a bed of conglomerate outcrops. At one place it is thirty feet thick and contains pebbles of granite, porphyry, and quartz embedded in a foliated quartzose matrix. Diabase dikes in the MacLeod-Cockshutt property do not outcrop, but occur only as fine-grained black dikes in the underground workings. A third difference is the presence of more iron formation in the MacLeod-Cockshutt than in the Hard Rock claims.

The Orebodies. The geology and structural relations of the ore deposits at MacLeod-Cockshutt have been investigated by H. F. Morrow.[8] He discussed three distinct types of orebodies at

[8] Morrow, H. F.: Geology and Ore Deposits of the MacLeod-Cockshutt Gold Mines, Little Long Lac Area, Ontario. (Unpublished M.A. thesis, Dept. of Geol., Queen's University, 1940.) Pp. 13–39.

Chalcopyrite (white—smooth contacts and presence as exsolution blebs suggest contemporaneity of chalcopyrite and sphalerite), sphalerite (gray), quartz (black). × 120.

FIG. 15. Hematite between quartz and pyrite in veinlet. MacLeod-Cockshutt Gold Mines Limited. Hematite (light gray band), pyrite (white), quartz (dark gray), magnetite (light gray grains scattered in pyrite). × 55.

FIG. 16. Ilmenite with pyrite and quartz. Bankfield Consolidated Mines Limited. Ilmenite (gray), pyrite (white—contains tiny inclusions of gold), quartz (black). × 110.

FIG. 17. Malachite, limonite, and chalcocite with chalcopyrite, pyrite, and quartz. Bankfield Consolidated Mines Limited. Pyrite (white euhedral grain), quartz (black), chalcopyrite (light gray), chalcocite (lighter gray bands in and around chalcopyrite), limonite (dark gray bands associated with chalcocite), malachite (radiating clusters of needles). × 110.

FIG. 18. Chalcopyrite and pyrite with chalcocite-limonite veinlets. Bankfield Consolidated Mines Limited. Chalcopyrite (light gray), pyrite (white), chalcocite (lighter gray bands in chalcopyrite) limonite (dark gray bands associated with chalcocite), quartz and calcite (dark gray). × 55.

the mine: the South Ore Zone, the North Ore Zone, and the 210 Quartz Vein. Recent developments since the summer of 1940 have indicated the presence of a fourth orebody, to be known as the West Ore Zone.

The South Ore Zone is one of fracturing and shearing, closely following the contact between the albitite porphyry and greywacke. Gold values are limited to the sheared rocks which include the porphyry where the tongues of that rock are narrow. Massive sulphides comprise the major ore minerals; in some places tongues of sulphides have replaced the greywacke along shear and bedding planes.

The North Ore Zone is composed of lenses of sulphides in a band of iron formation. The lenses are short and wide and lie close together along the contorted contacts between the more typical iron formation and greywacke containing a low percentage of iron. In places the structure of the ore shoots is very irregular with finger-like tapering ends. The sulphides have selectively replaced sheared greywacke along the shear planes, rather than the massive iron-rich bands. Many sulphide veinlets transect the shear planes of the greywacke where cross fractures afforded easy access of ore-bearing solutions. The stoping length of the ore zone is about 600 feet, the width averages 12 feet, but varies within much wider limits.

The 210 Quartz Vein is a closely folded saddle that lies entirely within the albite porphyry and contains visible gold. The vein, from which irregular quartz stringers branch, overlies an anticlinal mass of greywacke.

The West Ore Zone, 1,400 feet west of the North Ore Zone, comprises lenses of sulphides in iron formation that has been drag folded, and dips north at 68°. As in the North Ore Zone, the sulphides have selectively replaced the softer sheared portions of the iron formation. Several quartz veins containing free gold were found in the greywacke immediately south of the iron formation. A single specimen, part of a drill core, is composed almost entirely of pyrrhotite, but contains considerable free gold.

Production figures show that, in the year ending September 30, 1941, 240,098 tons of ore were milled for an average recovery of $9.52.

Mineral Paragenesis (Fig. 15). The mineralogy at the MacLeod-Cockshutt mine is similar to that at Hard Rock. Ten metallic minerals were identified, and three minerals were tentatively identified as tellurides. Pyrite is the most abundant sulphide as arsenopyrite is less common than at Hard Rock. Free gold was found in more than half the polished sections and in some of the hand specimens.

The mineral sequences have been compiled for each of the ore zones in the following tables:

TABLE 3.

210 QUARTZ VEIN.

Quartz	--------
Pyrite	--
Fracturing	xxx
Krennerite (?)	-
Galena	-------
Gold	-------
Coloradoite (?)	?--?
Mineral X	?--?

TABLE 4.

NORTH ORE ZONE.

Arsenopyrite	---
Pyrite	--------
Quartz	-----
Local Fracturing, elsewhere	continuity
Quartz	----
Pyrrhotite	----
Sphalerite	--
Chalcopyrite	----
Leucopyrite	---
Jasper	---
Hematite	---
Fracturing	xxx
Quartz	----
Calcite	----
Gold	---
Pyrite	---

TABLE 5.

SOUTH ORE ZONE.

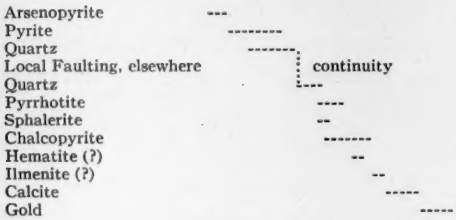


TABLE 6.

WEST ORE ZONE.

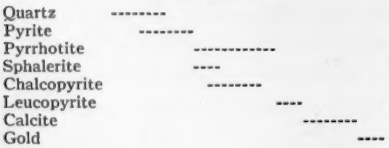


Table 3. The specimens from this high-grade vein contain spectacular amounts of free gold. The sections are composed almost entirely of gold, galena, and quartz with very minor amounts of pyrite and several minerals identified as tellurides.

Quartz was the first mineral to crystallize and in almost all cases is automorphic against pyrite, the second mineral. Pyrite is represented by only a few small grains, which rarely show crystal faces against the quartz. Quartz and pyrite were fractured during a period of movement, and the fractures filled with galena and gold. The walls of the fractures are generally ragged, due to this replacement. The relation of gold and galena to one another indicates they were contemporaneous; as many cases of gold conform to galena as the reverse. A lath-shaped mineral identified as krennerite (?) which was found in the galena is due to prior crystallization or automorphic replacement. Galena and gold are replaced by coloradoite (?) and an undetermined mineral X but the relations of these two minerals to one another are unknown.

Table 4. In all specimens from this zone arsenopyrite occurs as euhedral crystals, some of which are fractured. Crystals and masses of pyrite conform to arsenopyrite, and to a slight extent, to quartz. In general, quartz conforms to pyrite, but there is a little overlap in the relationship. Some sections contain arsenopyrite, pyrite, and quartz which are fractured; in other sections no fracturing of this period is indicated, but the deposition of quartz continued. Pyrrhotite, sphalerite, and chalcopyrite occur in much the same mutual relationship as in the Hard Rock ores, but are somewhat overlapped by quartz, which rarely conforms to these minor sulphides. Leucopyrite occurs as minute prisms and dendrites which conform to and replace those minerals which precede it in the table. Jasper and hematite were not observed in contact with leucopyrite, but it is probable that they are later. Both occur in fractures in fairly massive pyrite (Fig. 15) which contains blebs of the minor sulphides. Jasper was deposited first; hematite conforms to its outlines and is found in the middle part of the fracture fillings. Later fractures are filled with quartz and calcite which are in overlap relationship; most of the calcite conforms to the quartz, but the reverse is not uncommon. Gold was probably brought in by these late solutions. It conforms to calcite and all other minerals.

The late pyrite noted in the table occurs as drusy coatings in fractures in some of the hand specimens.

Table 5. Except for a greater overlap of quartz and pyrite, the sequence of minerals in this zone is the same as that in the North Ore Zone, as far as the end of the minor sulphides mineralization. In one specimen chalcopyrite is the dominant sulphide. Hematite, which is later than pyrrhotite in most places, conforms to chalcopyrite, but there is evidence that it is partially replaced by chalcopyrite in other specimens. A mineral identified as ilmenite conforms to every other mineral except calcite and gold. Calcite conforms to all those minerals which precede it in the table, but presents crystal faces to the minute grains of gold which was apparently the latest mineral.

Table 6. Only one polished section was available; it is noteworthy for the high proportion of pyrrhotite, and lack of arsenopyrite. Quartz was the first mineral to crystallize, closely followed by pyrite. In most cases quartz is automorphic against pyrite, but the reverse is not unusual. Pyrrhotite and sphalerite were deposited together following pyrite. Chalcopyrite overlaps sphalerite and is automorphic against some of the pyrrhotite. Deposition of pyrrhotite probably continued through rather a long period. Leucopyrite is fairly closely related to pyrrhotite, to which it conforms and which in part it replaces. Calcite conforms to all the minerals which precede it in the table, but presents its own crystal outlines against gold. As before, gold is the last mineral to be deposited; it was deposited in open spaces and also has replaced some of the sulphides.

Little Long Lac Gold Mines Limited.

General Geology. The geology and ore deposits of the Little Long Lac mine have been the subject of several papers by E. L. Bruce [9, 10, 11] and by E. L. Bruce and W. Samuel.[12]

The rocks in the vicinity of the mine are similar to those of the Hard Rock and MacLeod-Cockshutt mines, comprising basic lavas, sediments, dioritic intrusives, and lamprophyric dikes. No albitite porphyries have yet been found near the orebodies at Little Long Lac.

The "Keewatin-type" basic lavas, which dip steeply southward, lie about one-half mile north of the mine shaft. They are not likely to be encountered underground because the veins are almost vertical.

[9] Bruce, E. L.: Little Long Lac Gold Area. Ont. Dept. Mines, 44, pt. 3: 33–43, 1935.

[10] ——: New developments in the Little Long Lac area. Ont. Dept. Mines, 45, pt. 2: 124–125, 1936.

[11] ——: Structural relations of some gold deposits between Lake Nipigon and Long Lake, Ontario. Econ. Geol., 34: 362–365, 1939.

[12] Bruce, E. L. and Samuel, W.: Geology of the Little Long Lac Mine. Econ. Geol., 32: 318–334, 1937.

The "Timiskaming-type" sediments consist of arkoses, greywackes, iron formation, and conglomerate, all of which are lenticular, partly a relict primary structure, and partly a result of folding. The arkoses contain feldspar in excess of the 25 per cent requisite to the name, but quartz is also abundant. The rock is easily distinguished by its granular texture and gray color on fresh fracture surfaces. Both underlying and overlying the arkose are beds of greywacke, finer grained and darker in color than the arkose. In general, the greywacke is massive and contains considerable chlorite, but parts of the overlying layer are somewhat slaty. The iron formation bears the same relation to the greywacke as at Hard Rock and MacLeod-Cockshutt, all gradations being noted between greywacke with hematite and magnetite lenses and the more characteristic banded iron formation. This rock forms two discontinuous bands in the lower part of the sedimentary series. Conglomerate does not outcrop near the mine, but some beds have been encountered underground.

A mass of diorite outcrops about 600 feet south of the ore zone. Underground developments have shown a narrow lamprophyric dike altered to calcite. Outcropping a little more than a mile west of the mine is a narrow diabase dike, trending north-south.

The major synclinal structure of the area of which Little Long Lac is a part is complicated by a large drag fold. The beds, which normally strike almost east-west, are dragged northward about 3,000 feet and then resume their original strike. Shear zones developed in the arkose after the folding strike east-west or just north of east, parallel to the slightly curved axial plane of the drag fold. Measurements show that there is a westward plunge of about 50° to the minor structure. During the folding period the iron formation underwent considerable thickening and thinning and developed intricate plications. At the same time the greywacke developed a rather uniform schistosity, whereas the arkose yielded with the formation of the shear zones.

The Orebodies. The orebodies are confined to shear zones in the arkose beds. The main lode, which strikes nearly east-west and dips steeply to the south, lies about 80 feet south of the axial

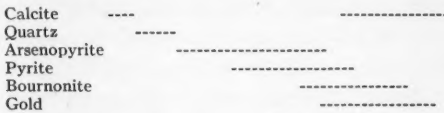
plane of the fold. In general, a single lode may be considered to be composed of two quartz veins 3 to 4 inches wide, separated by a sheared zone 40 to 50 inches wide containing numerous veinlets and stringers of quartz. The quartz veins are extremely variable in thickness, but remarkably continuous in length. Some veinlets only a fraction of an inch wide have been traced several feet. Although the veinlets ultimately pinch out, it has been found that others begin along parallel shear planes where the first veinlets end, thus maintaining a fairly constant proportion of quartz.

There are two main zones about fifty feet apart. Linking the two zones are veins which branch off from one main zone and join the other in a reverse curve. These veins plunge eastward in a direction almost perpendicular to that of the drag fold and may represent the original bedding. From the 11th to the 16th levels, the main vein is displaced southward by faulting a distance of about 150 feet.

In the typical lode described above, each of the two quartz veins may assay as high as 20 oz. of gold, but the average is 3 to 5 oz.; the intermediate zone, carrying sulphides, averages about 0.15 oz. It has proved economical to mine out the entire width which then averages about 0.5 oz. gold per ton. The main lode is 800 to 1,200 feet in length and has been developed to 2,200 feet with sixteen levels. During 1941, an internal shaft was sunk from the 16th level in order to open up four new levels. Lateral development is progressing and the vein has been reached on the 17th level. Production figures for 1941 show tonnage milled as 118,-332 for a recovery of $13.82 per ton. Ore reserves at the end of 1941 were estimated at 440,000 tons averaging $15.67 per ton in gold.

Mineral Paragenesis. In the examination of polished sections from this mine, nine metallic minerals were identified and a tenth tentatively identified. Arsenopyrite and pyrite are again the most abundant sulphides, occurring in about equal proportions. Free gold was observed in about half the sections examined; it was also observed in many of the hand specimens.

Bruce [13] outlined the following table of paragenesis in his study of this mine.



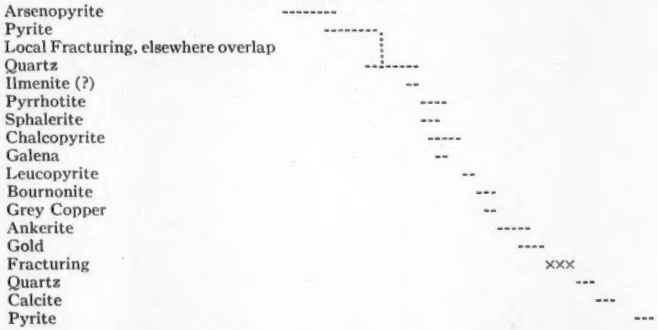
An important difference between this table and that of the writer, which is given below, is in the respective positions of the metallic and the nonmetallic minerals. In addition to the minerals listed in his diagram, Doctor Bruce identified stibnite and suggested that bismuthinite also might be present.

Ellis Thomson [14] examined polished sections of Little Long Lac ore and found limonite, hematite, magnetite, and berthierite in addition to several other minerals which were also identified in the present investigation. None of these four minerals was identified in any of the sections available to the writer.

The following table presents the sequence of minerals at Little Long Lac as observed in the present work:

TABLE 7.

LITTLE LONG LAC.



Discussion of the Table. In almost every specimen, arsenopyrite was the first mineral to crystallize, as shown by the pre-

[13] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., p. 40.

[14] Thomson, Ellis: Mineralization of the Little Long Lac and Sturgeon River Areas. Toronto Univ. Studies, Geol. Ser., 38: 38–41, 1935.

ponderance of euhedral over anhedral grains. Whether the grains are diamond or lath-shaped in outline depends upon their orientation in the polished section. The overlap relationship of pyrite and arsenopyrite is suggested in a few places where pyrite is automorphic against arsenopyrite. In some specimens, the arsenopyrite and pyrite are fractured, the cracks being filled and their walls partially replaced by metallic and nonmetallic minerals. In other specimens, no period of fracturing is apparent and quartz was deposited in overlap relationship with pyrite. Quartz always conforms to the crystal outlines of arsenopyrite, or replaces it, and with the exception noted above, is later than pyrite.

The position of the mineral temporarily identified as ilmenite is not very certain. It is probably contemporaneous with the last of the early quartz. Pyrrhotite, sphalerite, and chalcopyrite occur in very much the same relationship to one another as in the Hard Rock ores. They are all later than quartz, and occur as grains and blebs in the gangue, as well as in the major sulphides. Chalcopyrite was seen in several sections filling fractures in pyrite and arsenopyrite, and slightly replacing these minerals. Galena was found in a few specimens where it was automorphic against some chalcopyrite and sphalerite. Mutual boundaries between galena and these two minerals in other places suggest overlap. While leucopyrite was not observed in contact with chalcopyrite, it is later than pyrrhotite, which it sometimes replaces. The major and minor sulphides are automorphic against, or sometimes replaced by, bournonite, but no contacts of leucopyrite and bournonite were seen. Gray copper occurs as small blebs and grains which have mutual boundaries with some of the bournonite. It also occurs as replacement and space-filling blebs in the major sulphides. The mineral identified as ankerite conforms to the outlines of all the minerals which precede it in the table; a few replacement contacts were also observed. Although it is generally automorphic against gold, there were several places where it conformed to the gold outlines, indicating overlap of the two minerals. A second period of fracturing is suggested by the fractures in the quartz and ankerite of the sections. Fractured gold was not observed, probably be-

cause of the small size of the gold grains. The fractures were filled with a quartz-calcite mixture in which quartz crystallized first. The presence of pyrite crystals on the crystals of calcite in one of the hand specimens indicates the late pyrite shown in the table. A specimen of Little Long Lac ore recently sent to the writer contains the mineral scheelite. It was not possible to determine its age relations with all the other minerals, but the fact that it occurs in quartz veins and is cut by later quartz veinlets indicates that it is older than the later quartz. Information supplied by W. Samuel states that the mineral occurs as bunches and blebs in the main vein and in 409 vein. It also occurs as a veining mineral in the rock adjacent to the quartz veins. In 409 vein scheelite averages about three or four pounds per ton; the general average for the two occurrences is somewhat lower, about two pounds per ton.

Magnet Consolidated Mines Limited.

General Geology. The rocks in the vicinity of the mine comprise sediments, intrusive porphyries, and diabase. There are no outcrops in the immediate vicinity; bedrock is covered by a heavy overburden about fifty feet in depth.

The sediments consist of greywacke, conglomerate, and iron formation. The shaft was sunk in a wide band of greywacke. About 100 feet south of the shaft, the greywacke becomes fine grained and then makes a sharp contact with a black slaty rock containing small relatively sparse pebbles which are all highly carbonatized. This conglomerate, like other slaty horizons, is greatly thickened near the axes of minor folds and varies from 30 to 150 feet in thickness. To its south is a band of sericitic quartzite, probably a sericitized relatively coarse band of greywacke. This band is about 100 feet wide and is succeeded on the south by more greywacke. About 400 feet north of the shaft, a pinching and swelling band of contorted iron formation is indicated by diamond drill intersections and dip-needle surveys. A very minor discontinuous band of iron formation strikes slightly to the right of the vein. It crosses the vein at about the center of the ore zone, which is characteristically heavier in sulphides but leaner at the intersection.

About one-third of a mile northwest of the shaft is a body of porphyry which is probably the same as that on the Bankfield property. It should, therefore, be more correctly termed albitite porphyry. A few hundred feet north of this is a mass of diorite or dioritic porphyry. Recent developments have disclosed the presence of a mass of diorite in the shaft below the 1080-foot level. Several narrow but apparently persistent diorite dikes occur to the north of the vein on the 2nd level and a relatively small dike-like mass of porphyry has been indicated by drilling at about 300 yards northwest of the shaft. A diabase dike about 12 feet wide cuts across the vein almost at right angles, dipping steeply to the west. Nine hundred feet east of the shaft there are several north trending diabase dikes. One of these dikes, about 60 feet wide, may possibly mark a fault which has displaced the east continuation of the band of arkose about 170 feet south. This displacement, however, may be due to folding.

The Orebodies. The ore at Magnet Consolidated occurs in two parallel quartz veins which are bordered by narrow zones of sericitization. Intense sericitization colors the rock greenish buff for an inch or less from the quartz beyond which, for a few inches or more, the rock is usually perceptibly lighter colored than is the normal greywacke. In some instances a narrow zone of heavy sulphides continues along the strike beyond where the quartz pinches out. Although of good grade, this material is usually too narrow to mine. There are no indications of shearing or faulting in the country rock along the strike of these zones. The width of the veins in the upper levels of the mine averages about three feet, and their trend is N75° W with a dip of about 80° to the south. In the lower levels, the veins average twelve to eighteen inches but the ore shoot is considerably longer than in the higher levels. The dip of the veins here varies from steeply south to steeply north. The veins are developed in medium grained greywacke which has been dragged into a well-developed fold plunging at about 45° to the west. The orebodies rake to the west at about the same angle.

The average ore on the lower levels in the mine contains a high proportion of arsenopyrite. This ore is quite distinct from the

quartz with gold and galena—high grade material—which is particularly abundant in small structures resembling folds in the veins. These structures, according to P. C. Benedict[15] occur in places where the greywacke shows no minor folding. One of the best developed of these plunges east at about 45°, a direction just opposite that of the drag folding. Benedict believes these structures to be "due to the quartz locally following the tension element of the shear pattern for a very few feet."

The main ore shoot has been developed down to the 1080-foot level, where it is 850 feet in length. Drifting on the 1380- and the 1730-foot levels has disclosed continuation of the orebodies. During 1941, a short shoot of marginal ore was developed in a small vein lying about 600 feet north of the main ore shoot. Production figures for 1941 show 47,731 tons mined. The average recovery, after sorting, was 0.556 oz. per ton.

Mineral Paragenesis (Figs. 6, 12, 13). The mineralogy of the ores from this mine is not complex. Seven metallic minerals were identified, the chief of which is arsenopyrite. Pyrite is present in somewhat minor amount. Free gold was observed in many of the polished sections and hand specimens. It was present in spectacular amount in one specimen from the drag fold on the 1080-foot level.

The following table has been drawn up to represent the sequence of mineralization:

TABLE 8.

MAGNET CONSOLIDATED.

Arsenopyrite	--------
Pyrite	----
Fracturing	xxx
Quartz	------
Pyrrhotite	---
Chalcopyrite	-----
Leucopyrite	----
Calcite	------
Galena	----
Gold	----
Fracturing	xxx
Quartz	---
Calcite	---

Discussion of the Table. Arsenopyrite, as in many of the other mines, was the first mineral to crystallize. The characteristic

[15] Benedict, P. C.: Personal communication.

euhedral outlines are supplanted in some sections by ragged borders due to replacement of arsenopyrite by later minerals. Pyrite usually conforms to arsenopyrite, but one specimen was examined in which pyrite was, in part, the earlier of the two. Since this relationship was observed in only one section, it is indicated by only a slight overlap in the table. In most of the sections, arsenopyrite and pyrite have been fractured, the fractures being filled with metallic or nonmetallic minerals. In other sections there is no evidence of this fracturing and quartz was deposited directly after the pyrite. In all cases quartz is definitely later than the pyrite and conforms to, or replaces, both pyrite and arsenopyrite. Pyrrhotite conforms to the major sulphides and to quartz. It occurs as replacement and space-filling blebs in the major sulphides and in some sections fills cracks. Chalcopyrite occurs in overlap relationship with pyrrhotite; in most places it conforms to pyrrhotite (Fig. 13), but their presence in segmented veinlets in fractured arsenopyrite suggests they are contemporaneous. In a few instances the contacts were such as to suggest that chalcopyrite was the first to crystallize.

Leucopyrite (Fig. 12) was observed in contact with pyrite, pyrrhotite and arsenopyrite. It is distinctly later than pyrrhotite and is probably later than chalcopyrite, although the contact was not observed. Calcite conforms to the tiny prisms and dendrites of leucopyrite. Crystal faces of chalcopyrite and pyrrhotite against calcite also were observed. Galena and gold are essentially contemporaneous (Fig. 6), an equal number of crystal faces of each against the other being found in the sections. Their contacts, if not those of crystal faces, are entire and rounded, rather than ragged replacement contacts. The presence of gold along cleavage planes in calcite in one hand specimen, and the conformity of both galena and gold to calcite in the polished sections indicate their respective ages. One of the hand specimens shows a veinlet of quartz and calcite cutting across the other minerals. It is a fracture filling because the opposite walls match perfectly. Its segmented character indicates quartz and calcite are contemporaneous.

Bankfield Consolidated Mines Limited.

General Geology. The geology and ore deposits of the Bankfield mine have been the subject of papers by A. W. Johnson [16] and E. L. Bruce.[17, 18, 19]

The rocks in the vicinity of this mine, continuous with those at Tombill, comprise sediments, albitite porphyry, and diorite. The sediments include greywacke, slaty greywacke, conglomerate, and iron formation, of which the greywackes and argillite-like greywackes are the most important. The beds strike almost east-west dipping steeply to the south, but have been fractured and sheared by later deformation. Some of the coarser greywacke has been silicified by solutions from the feldspar porphyry masses.

The sediments are intruded by masses of diorite and albitite porphyry. Diorite occurs as dikes and irregular masses. Some of the more regular masses may actually represent recrystallized volcanics interbedded with the sediments. The albitite porphyry occurs in dikes and elongated lenticular masses striking east-west and dipping steeply to the south. These porphyry masses have been somewhat fractured by the movements which sheared the sediments.

The Orebodies. The original work was done on the North zone which contained some gold but no commercial ore. The entire production of the mine has come from the South zone.

The South zone is continuous with the Tombill orebody, consisting, therefore, of a sheared and fractured zone at the contact of albitite porphyry, greywackes, and lean iron formation. Mineralization is fairly heavy, gold values and sulphides being disseminated in irregular lenses in the sheared rock and in the quartz-filled fractures. One section of the South zone strikes east-west and dips south at about 75° over a length of 275 feet up to the

[16] Johnson, A. W.: Geology and Ore Deposits of the Bankfield Gold Mine. (Unpublished M.Sc. thesis, Dept. of Geol. Queen's University, 1935.)

[17] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., pp. 46–50.

[18] ——: New developments in the Little Long Lac Gold Area. Op. cit., pp. 135–140.

[19] ——: Structural Relations of some gold deposits between Lake Nipigon and Long Lake, Ontario. Op. cit., p. 361.

east boundary of the Tombill property. The types of ore in this section have been discussed by Doctor Bruce.[20]

The other section in the South zone lies to the south of the Tombill property. The Tombill vein dips into the Bankfield below the 525-foot level, and has been developed by a winze sunk from that level about 1,700 feet west of the main shaft. Production figures for the eleven months ending October 31, 1941, show 36,072 tons milled at an average recovery of $6.82 per ton.

Mineral Paragenesis (Figs. 4, 8, 16, 17, 18). The Bankfield mine is the only one in this area for which supergene minerals were recorded. Eight hypogene and three supergene metallic minerals were identified in the polished sections. Free gold was observed in most of the sections and in a few hand specimens.

In his study of the ores, Johnson [21] found three periods of fracturing marking the intervals between deposition of arsenopyrite, pyrite, ilmenite, and pyrrhotite and chalcopyrite, respectively. He found no time break between pyrrhotite and chalcopyrite. The present work indicates two periods of fracturing; one in the middle of mineralization, the other at the end, during which fissures were formed and filled with quartz and calcite.

The following table illustrates the sequence of minerals of the Bankfield ores.

TABLE 9.
BANKFIELD

Arsenopyrite	------
Pyrite	--------
Fracturing	xxx
Quartz	-----
Ilmenite	--
Pyrrhotite	----
Sphalerite	---
Chalcopyrite	-----
Grey Copper	-
Calcite	----
Gold	---
Fracturing	xxx
Quartz	---
Calcite	---
Chalcocite }	--
Limonite } Supergene	---
Malachite }	---
Calcite }	---

[20] Bruce, E. L.: New developments in the Little Long Lac Area. Op. cit., pp. 138–140.

[21] Johnson: Op. cit., p. 23.

Discussion of the Table. Arsenopyrite is rather subordinate in quantity to pyrite, but in many cases is the earlier of the two minerals. Skeleton crystals are common in which one or more faces are not developed perfectly. Pyrite presents its own crystal outlines to all other minerals (Fig. 4) sometimes including arsenopyrite. Both pyrite and arsenopyrite are fractured, particularly the larger crystals. Small perfect crystals are considered to be of the same age as the larger but fractured crystals. Quartz was deposited immediately after the period of fracturing; many of the fractures in the major sulphides have been sealed with quartz or minor metallics. Ilmenite (Fig. 16) conforms to quartz, but itself is automorphic against, or replaced by, the later minerals. Pyrrhotite, sphalerite, and chalcopyrite are related to one another in the same way as in most of the other mines, and are later than ilmenite. Gray copper is overlapped by chalcopyrite, but is later than pyrrhotite and sphalerite. It occurs as inclusions in pyrite in one polished section, where it appears to be later than pyrrhotite but contemporaneous with some of the chalcopyrite. Early calcite conforms to chalcopyrite and all the other minerals with the exception of gold. The exact position of gold in the sequence is not definite; it may be earlier than the second fracturing, or it may have been brought in by the solutions which followed that fracturing. One very high grade specimen contains considerable free gold which occurs as blebs and veinlets in quartz and pyrite (Fig. 8). The veinlets are of the replacement type; the blebs are commonly outlined by smooth crystal faces of quartz or pyrite. None of the sections examined shows the second period of fracturing. Many of the hand specimens, however, are cut by veinlets of quartz and calcite in which the calcite is located medially, conforming to the crystal outlines of quartz.

The supergene minerals are interesting in their relationships. Pyrite and chalcopyrite are intricately laced with networks of chalcocite and limonite veinlets showing the abrupt ends characteristic of replacement (Fig. 18). In these ribbon-like veinlets chalcocite lies nearest the primary mineral. Limonite forms

a narrow strip down the middle of the veinlets; it is later than the chalcocite. Malachite (Fig. 17) was found in only one part, where it forms a cluster of fine green needles radiating outward from the limonite rims of a chalcopyrite grain. Close to this group is another cluster of brown needles of limonite or goethite. The similarity of occurrence of the two clusters suggests an overlap in the relationship between the two minerals. Calcite has filled the interstices between the needles of malachite; their relative ages are thus indicated.

Tombill Gold Mines Limited.

General Geology. The rocks in the vicinity of the Tombill mine are covered by about ninety feet of glacial drift. Those encountered in the underground workings are the same as those in the adjoining Bankfield mine.

Greywacke occurs in parallel bands and lenses striking N72° W, and dipping steeply to the south. Several varieties have been mapped, including chloritic and arkosic greywackes. The sediments have been intruded by diorite and by quartz-feldspar porphyry. The latter is a continuation of the Bankfield rocks identified by E. L. Bruce [22] as an albitite porphyry. It occurs as elongated lenticular masses in the diorite south of the vein and in the greywacke to the north. Where the intrusive character of the diorite is in doubt, it is possible that the rock is actually recrystallized volcanic material. The Tombill shaft is sunk in arkosic greywacke 75 feet north of the vein.

The Orebodies. There are two ore zones at Tombill, the North and the South. The South zone is a continuation of the main Bankfield ore zone, silicified at the contact of the diorite and the sediments and probably represents silicified greywacke or arkosic greywacke. This is the only zone in production. Underground developments over a length of 2,000 feet have disclosed six blocks of ore. The steep southerly dip carries the vein into the Bank-

[22] Bruce, E. L.: New developments in the Little Long Lac Area. Op. cit., pp. 137–138.

field property to the south below the 600-foot level. The annual report dated March 1, 1941, disclosed that the South ore zone has been fully prospected and that no further ore is expected. A fairly wide siliceous zone 300 feet north of the shaft is lightly mineralized but has yielded no ore.

The North ore zone lies about 2,000 feet north of the South, and contains a twelve-inch band of iron formation interbedded with greywacke, which is irregularly folded and carries low values. The possible ore of the North zone is associated with a narrow silicified quartz feldspar dike carrying some visible gold and scheelite but not in commercial quantities. A crosscut extending northerly from the second level station was driven more than 2,000 feet, but the results of the exploration work and drilling, including 430 feet of drifting, disclosed no ore under the present conditions. Some of the material was run through the mill, but proved to be too low grade.

The orebodies are generally lenticular in shape and their underground structure is not complex. Numerous minor faults have been encountered in the South ore zone. Most of these faults trend northwest and dip southwest. The most important fault dips about 42° to the southwest, the throw along it amounting to about 40 feet. The west end of the vein has been displaced to the north relative to the eastern extension.

During 1941, a total of 46,956 tons of ore was milled for a recovery of $10.81 per ton. Reserves at the end of 1941 were expected to be exhausted about September, 1942.

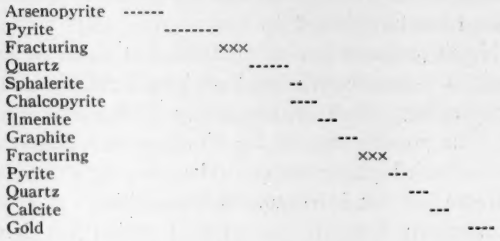
The property of Elmos Gold Mines Limited, lying three miles to the east adjacent to Little Long Lac and MacLeod-Cockshutt, has been acquired and is being dewatered. Ore from this property will be milled when the Tombill orebodies are exhausted.

Mineral Paragenesis (Figs. 5, 9, 10, 14). Polished sections permitted the identification of seven metallic minerals. Free gold was observed in almost all the specimens, two of the hand specimens being very high grade. One specimen contains a very high proportion of chalcopyrite, but pyrite is the conspicuous sulphide in the other sections.

The following table shows the sequence of minerals at Tombill:

TABLE 10.

TOMBILL.



Discussion of the Table. Arsenopyrite, although not present in every section, was the first mineral to cr tallize. It is euhedral against the other minerals except where it has been replaced. Pyrite in general is more abundant than arsenopyrite to which it conforms. Both arsenopyrite and pyrite were fractured during a period of movement which followed the crystallization of pyrite and preceded that of quartz (Fig. 5). The fractures in pyrite and arsenopyrite are filled with quartz and metallic minerals. Quartz conforms to the major sulphides, but presents its own crystal outlines to the other minerals (Fig. 10). The Tombill ores are noteworthy for the lack of pyrrhotite in all the sections examined by the writer. Sphalerite and chalcopyrite are in overlap relationship (Fig. 14); both are conformable to quartz. Chalcopyrite filled a few cracks in the fractured sulphides and apparently had a longer period of deposition than sphalerite. Conforming to, and partially replacing, chalcopyrite are irregular grains of ilmenite. The relations of ilmenite and graphite were not observed, but graphite is distinctly later than the chalcopyrite. Some graphite may have been developed during the second period of movement which caused fracturing of the earlier minerals.

The second period of fracturing is best shown in the hand specimens, where the earlier quartz is transversed by fracture veinlets of contemporaneous quartz and calcite. The polished sections

show tiny euhedra of pyrite in some of these veinlets; it is earlier than the quartz or calcite. Gold was apparently introduced after the second fracturing. It occurs as fracture fillings in the early quartz and is later than the chalcopyrite with which it is sometimes associated. In the high grade sections, gold occurs with pyrite and arsenopyrite, sometimes replacing them, in other places surrounding euhedra of the sulphides with no apparent action on them (Fig. 9).

Jellicoe Mines (1939) Limited.

General Geology. The ore deposits at the Jellicoe mine are associated with sediments and intrusive porphyries. Bedrock in the vicinity of the mine is covered with a heavy overburden of glacial drift about 50 feet thick.

The sediments comprise greywackes grading into "arkoses," [28] and slaty greywackes, some of which carry considerable chlorite. The shaft is located in a broad belt of chloritic greywacke striking just north of west. A 400 foot band of "arkose" which lies 50 feet south of the shaft contains the Main Zone orebodies. About 900 feet north of the shaft is a narrow band of iron formation; a second band of iron formation about half a mile south of the shaft is believed to be a different band.

Just north of the shaft a narrow band of rock, which parallels the trend of the greywacke, has been identified as a diorite sill. The difficulty of distinguishing between intrusive diorite and recrystallized interbedded volcanic material has been noted elsewhere. It is possible that the so-called diorite is such an interbedded volcanic rock.

About 700 feet north of the shaft, a band of rock trends just north of west; it is known at the mine as the "Quartz-feldspar Marker." A similar rock type on the adjacent Tombill property is called quartz-feldspar prophyry. Specimens of these rocks were found to be very similar to the albite porphyry at the Bank-

[28] The term "arkose" as used at this mine is applied to a light-colored rock which may actually be an altered and bleached greywacke.

field mine. The "Quartz-feldspar Marker" is an almost vertical dike cutting across the greywacke at a small angle.

An irregular mass of porphyry associated with conglomerate and chloritic greywacke extends into the property about one mile south of the Jellicoe shaft.

The Orebodies. The Main Zone orebodies are confined to vein quartz and silicified and brecciated zones in the band of arkose just south of the shaft. This band dips to the southwest at 75° to 80° along its northwest strike. Two sections, the eastern and western, of the Main Zone have been developed.

The arkose of the Eastern section is partially silicified and differs from the ore shoots only in its lesser degree of silicification. Free gold was observed only where there is almost 100 per cent quartz. The main structure, as determined by G. C. McCartney,[24] Consulting Geologist for the mine, is in the form of a flat "S"; this "S" appears both in plan and in section. The ore of the first level main break forms the body of the "S." On the second level small, flatly westward pitching veins appear as large drags when viewed in plan. A feature of these veins is the variation in the development of vein quartz; in some places, general zones of silification take the place of vein quartz. All veins and ore occurrences appear to follow crush or fault zones in the arkose. The tailing out ore zone is displaced by a fault about 200 feet west of the shaft. This fault strikes just east of north and dips steeply to the southwest. Beds on the west of the fault are displaced northward about 200 feet relative to the same beds on the east of the fault.

The so-called Western section of the Main Zone was thoroughly diamond drilled from the surface. During the first seven months of 1940 a 2,000 foot drift was run on the 500-foot level from the Eastern section. Further drilling from this location failed to prove anything approaching an economic deposit. Operations by the present company were discontinued permanently on this property in August, 1940.

A total of almost 14,000 tons of ore from the Eastern section

[24] McCartney, G. C.: Private report to the directors.

was treated at the Magnet and Bankfield mills. The grade averaged almost 0.4 oz of gold per ton.

Mineral Paragenesis. The mineralogy at the Jellicoe mine is not complicated. Eight metallic minerals were identified. Arsenopyrite is more abundant than pyrite. Free gold was observed in more than half the polished sections, and in a few of the hand specimens.

The sections and hand specimens indicate only one, a rather late, period of fracturing. The composite table illustrating the mineral sequence is as follows:

TABLE 11.

JELLICOE.

Discussion of the Table. Arsenopyrite was the first mineral to crystallize and in every section its crystal outlines were exhibited against all others except where it has been partially replaced. Pyrite conforms to, or replaces, arsenopyrite, but in turn is automorphic against the later minerals. A period of deposition of quartz interrupted the sequence of sulphide mineralization. The quartz was followed by pyrrhotite, sphalerite, and chalcopyrite in the order in which they are found in most of the other mines of the area. The chalcopyrite is fairly abundant as replacement veinlets and blebs in the gangue and in the major sulphides. A hard gray mineral with the characteristics of ilmenite was observed in several sections where it follows the minor sulphides, and in contact with chalcopyrite which it had partially replaced. Stibnite was identified in only one section. It was not seen in

contact with ilmenite, but the character of its contact with chalcopyrite indicates that it is the later of the two.

The evidence for a period of fracturing was observed in a single section where a barren quartz-calcite veinlet cuts the sulphides and quartz. Similar veinlets were seen in several hand specimens. In these veinlets quartz crystallized prior to calcite. In some sections, calcite was deposited from fracture-filling solutions which penetrated beyond the fissures. Gold was carried in by these solutions and in several places conforms to the calcite. In unfractured sections, the gold fills spaces between the earlier minerals. Drusy pyrite was observed in some of the hand specimens, where it was deposited in fractures on the second generation of quartz.

SUMMARY AND CONCLUSIONS.

General Paragenesis.

In the early days of development in the Little Long Lac area, Ellis Thomson [25] examined a collection of specimens. As a result of his study, Thomson outlined a general order of mineral deposition as follows:

1. Quartz, pyrite, arsenopyrite, magnetite.
2. Quartz, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, carbonate.
3. Carbonate, pyrite, berthierite, sphalerite.
4. Galena, gold, tetrahedrite.
5. Limonite.

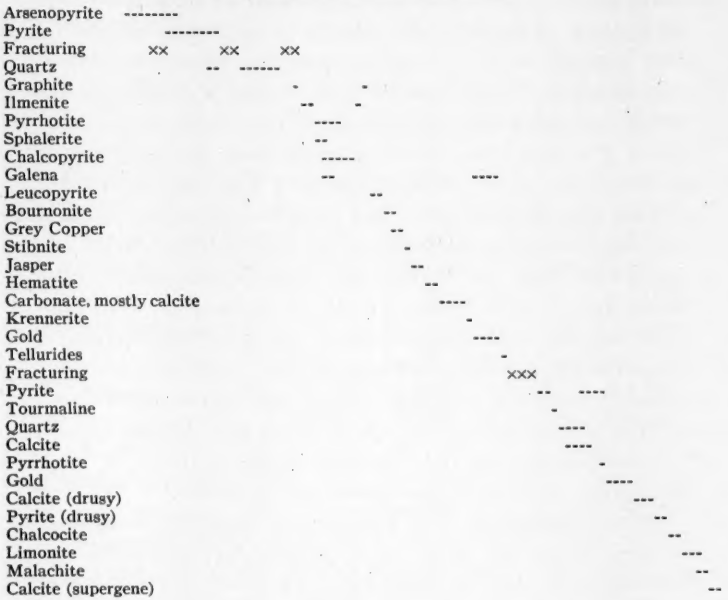
In the course of the present work, the writer found no magnetite which showed evidence of being introduced with the mineralizing solutions. Considerable magnetite was found in the iron formation ores from Hard Rock and MacLeod-Cockshutt, but it is not related to the sulphides which have replaced parts of the iron formation. Other differences from the earlier work are apparent in the table which follows. This table represents a generalization

[25] Thomson: Op. cit., pp. 38–41.

of the broader areal relations together with as much detail as could be included. Many of the eleven individual tables show considerable differences, but certain features of each appear to be characteristic of the area as a whole.

TABLE 12.

GENERAL SEQUENCE OF MINERALS.



Discussion of the Table. The order of deposition of the first three, and most abundant, minerals is almost everywhere the same (Figs. 1, 2, 4), but the arsenopyrite does not occur in all the orebodies. During this period of deposition, there was considerable movement which resulted in fracturing of the mineral or minerals already crystallized. The time of fracturing varies from place to place; generally two minerals were fractured, but in places only

one or all three minerals were fractured (Figs. 3, 5, 7). In some cases, this early period of fracturing is lacking.

In almost every mine, pyrrhotite, sphalerite and chalcopyrite occur as blebs and veinlets in the major sulphides and quartz (Fig. 11). Their order of deposition and mutual relationships are the same in each place, even if one of the three is missing. Chalcopyrite and pyrrhotite are abundant locally (Figs. 10, 13), but sphalerite never forms a major part of the ores (Fig. 14). The relationships of graphite and ilmenite to each other and to the other minerals are not nearly as constant as those of the above three minerals. Neither graphite nor ilmenite is abundant in any section. Graphite was observed in only two mines; in one it was deposited during movements which followed the deposition of quartz, in the other it is distinctly later than chalcopyrite and probably later than ilmenite. Ilmenite was observed in specimens from seven different orebodies (Fig. 16); in three of these it precedes pyrrhotite, in the other four it is later than chalcopyrite. Galena, also, does not show constant relationships. It was identified in sections from four orebodies; in two of these it occurs with pyrrhotite, sphalerite and chalcopyrite in overlap relationship, in the other two it is later than chalcopyrite and contemporaneous with the early gold (Fig. 6). In the latter cases, galena forms a fairly high proportion of the sections as distinct from its minor development when closely associated with sphalerite.

Stibnite, leucopyrite (Fig. 12) and the sulpho-salts bournonite and gray copper are found locally and in very minor amount. Their respective ages are indicated in the table; everywhere they are later than chalcopyrite and earlier than gold or the later fracturing.

The jasper and hematite noted in the table occur in a section from the North Ore Zone at MacLeod-Cockshutt (Fig. 15). They are included here for the sake of completeness. In that section they are later than leucopyrite but earlier than the late fracturing. A second or late period of fracturing is indicated in specimens from almost every orebody. Preceding this fracturing,

but later than the sulpho-salts in many of the sections, is an early carbonate, generally calcite. At Little Long Lac, however, ankerite occurs. The carbonate may be followed by gold or by galena and gold. This early gold was observed in specimens from several of the mines. Where the second fracturing is lacking, gold is associated with the carbonate. The euhedral lath-shaped crystal embedded in galena, as observed in one section from the 210 Quartz Vein at MacLeod-Cockshutt, is possibly the telluride, krennerite. It is possible that it may be an automorphic replacement of the galena, but it is considered to be a prior crystallization. Other telluride-like minerals from the same location are apparently later than the gold and galena which they have partially replaced.

The fractures which have resulted from the late fracturing are filled with quartz and calcite. In these veinlets, the quartz began to crystallize first, but it is overlapped considerably by calcite. The veinlets commonly carry other minerals in addition to quartz and calcite. In sections from two orebodies pyrite was earlier than the late quartz; in another section it is later, overlapping the calcite deposition. Tourmaline in one section followed the pyrite but preceded quartz as shown in the table. Hand specimens from one orebody were cut by veinlets containing pyrrhotite with quartz, calcite and pyrite. The pyrrhotite is later than the calcite, but is contemporaneous with the later part of the pyrite. Gold is associated with many of these veinlets where it was deposited late in the sequence. Early and late gold were not found together in any one section. It is possible that both ages may be represented in some of the high grade specimens (Figs. 6, 7, 8, 9) but no criteria for distinguishing between them were found. It has been suggested that gold very closely associated with pyrite may have been in solid solution. Spectrographic investigations recently reported by P. E. Auger [26] indicate, however, that gold takes no part in the structure of pyrite crystals as solid solution, but rather occurs

[26] Auger, P. E.: Zoning and district variations of the minor elements in pyrite of Canadian gold deposits. Econ Geol., 36: 412, 1941.

as later replacements or fracture fillings. These findings are quite in accord with the observations made during the present study.

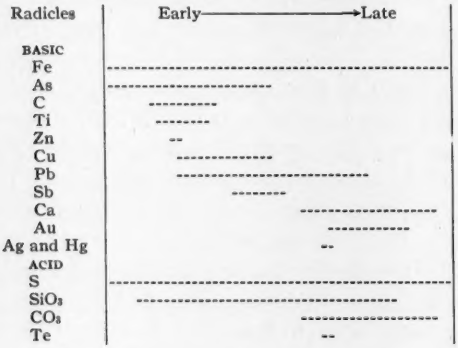
Drusy coatings of calcite and pyrite were observed in several hand specimens from different parts of the area. They probably represent the last slow percolations of the ore-bearing solutions.

The presence of chalcocite, limonite, malachite (Figs. 17, 18) and supergene calcite completes the table and indicates the action of downward enrichment and oxidation.

It is apparent from Table 12 that the mineralization in the Little Long Lac area is almost entirely hypogene. It has been considered advisable to express the sequence in terms of the radicles present in the mineralizing solutions as well as in terms of the combination of radicles as minerals. The sequence of radicles is presented in Table 13.

TABLE 13.

GENERAL SEQUENCE OF RADICLES.



Mineralogy.

The minerals which have been identified during the present study are listed in Table 14. Their position in the sequence of mineralization and the genetic conditions under which they were deposited are indicated.

TABLE 14.

	Hypogene			Supergene
	Early	Intermediate	Late	
Elements				
Graphite		R		
Gold		×	×	
Sulphides				
Arsenopyrite	×		R	
Chalcocite				R
Chalcopyrite		×		
Cubanite		R		
Galena		×		
Leucopyrite		×		
Pyrite	×		×	
Pyrrhotite		×	R	
Sphalerite		×		
Stibnite		R		
Sulpho-salts				
Bournonite		R		
Grey Copper		R		
Tellurides				
Coloradoite (?)		R		
Krennerite (?)		R		
Mineral X (?)		R		
Oxides				
Hematite		R		
Ilmenite		×		
Jasper		R		
Limonite				R
Quartz	×		×	
Carbonates				
Ankerite		R		
Calcite		×	×	R
Malachite				R
Tungstate				
Scheelite		R		

R indicates a rare mineral.

Character of the Ore Fluid.

Composition. The ore-bearing solutions contained the following elements: Ag, As, Au, C, Ca, Cu, Fe, Hg, Mg, Pb, Te, Ti, Si, S, Sb, W, Zn, and H_2O. Bruce [27] reports in the analysis of mill heads from the Little Long Lac mine, the occurrence of bismuth. No bismuth minerals were observed in the present work.

Wall rock alteration was not studied by the writer. Accord-

[27] Bruce, E. L.: Little Long Lac Gold Area. Op. cit., p. 40.

ing to Bruce[28] wall rock alteration is not intense except for silicification in some zones, where there has been a considerable development of pyrite. Carbonatization has occurred in some places.

Morrow's[29] study at MacLeod-Cockshutt shows considerable alteration of greywacke and porphyry adjacent to the ore zones in the South orebody. He found a gain in K_2O, Al_2O_3, CaO, MgO, CO_2, H_2O, FeO, and FeS_2; losses were recorded in SiO_2, Na_2O, and Fe_2O_3. The gain in potash and alumina represents sericitization; that in lime, magnesia, ferrous oxide, and carbon dioxide represents carbonatization. The increase in FeS_2 represents the dissemination of pyrite through the wall rock. These results indicate that the ore-depositing solutions were alkaline in character, at least so far as the ores of the South ore zone at the MacLeod-Cockshutt mine are concerned. The answer to the question as to whether the solutions were acid or alkaline at greater depths must await further developments of the area.

Temperature. A method for distinguishing between alpha and beta quartz has been developed by V. B. Meen, who applying it to specimens of tourmalinized vein quartz from the Little Long Lac area, found that three specimens showed low-temperature, and three showed high-temperature, characteristics.[30] A specimen of quartz with tourmaline and gold, from the same region, showed high-temperature characteristics. Lindgren[31] has expressed the opinion that, in mesothermal deposits, there are only rare exceptions from the sequence, pyrite preceding arsenopyrite. Bandy[32] has recently developed a "normal sequence" theory. In his general paragenesis of hypothermal deposits, arsenopyrite crystallizes prior to pyrite.

[28] Ibid., p. 31.

[29] Morrow, H. F.: Op. cit., pp. 27–31.

[30] Meen, V. B.: The temperature of formation of quartz and some associated minerals. Toronto Univ. Studies, Geol. Ser., 38: 62, 1935.

[31] Lindgren, Waldemar: Mineral Deposits. 4th ed. rev. McGraw-Hill Book Co., Inc., New York. 1933. P. 544.

[32] Bandy, M. C.: A theory of mineral sequence in hypogene ore deposits. ECON. GEOL., 38: 556, 1940.

In the present study, the preponderance of the sequence arsenopyrite before pyrite, especially when considered in conjunction with Meen's results, indicates that the ore deposits may be allocated to Lindgren's hypothermal type. The occurrence of tellurides and the presence of galena and stibnite, however, indicate lower temperatures. It is possible, then, that the ore deposits of the Little Long Lac area are most correctly placed in the upper hypothermal, or lower mesothermal, zone.

Relations of the Ores to Intrusives.

The occurrence of dikes and larger masses of intrusive rocks has been discussed in the section on the general geology of the region. There appears to be no relation between the large albitite porphyry pipe and the ores at Hard Rock and MacLeod-Cockshutt. The porphyry is considerably earlier than the ores, as indicated by the presence of ore masses in cracks and fissures in the porphyry. The molten rock had been intruded, solidified, and fractured before the advent of the ore-depositing solutions. In the four westernmost mines in the area, some of the ores have been found in sheared and fractured porphyry and diorite. The possibility that the ores are genetically related to the porphyry must, however, be kept in mind until evidence to the contrary is found. During a long period of rhythmic violent earth movements, small elongate masses might be intruded along major planes of fracture where rapid cooling could take place. Subsequent movements would fracture and shear parts of these masses which might then serve as favorable loci for the deposition of ore minerals from solutions representing a late phase of the original source magma of the porphyries. The same movements that fractured the rock might aid in the circulation of the ore solutions.

A second possible source of solutions is from the granite masses which lie to the north and south of the belt of mines. Gray granite and pegmatite masses occur six to ten miles south, pink granites six to four miles north of the belt. It is possible that the ore solutions are consanguine with one or other of these rock masses.

The synclinal structure of the region suggests little except that, unless the lower part has been removed by igneous material, a considerable thickness must yet be penetrated before the original Laurentian(?) or Keewatin(?) floor is reached. The fact that the ore deposits occur along the same general strike, that is, parallel to the trend of the country, suggests that the syncline is truncated at depth. The planes thus opened provided easy access of ore solutions, especially when controlled either by structure or lithology or a combination of the two. This is in accord with a statement by E. S. Moore [33] to the effect that "in the Precambrian areas the gold commonly has been formed from solutions rising upward along limbs of synclines."

ACKNOWLEDGMENTS.

The officers of the various mines who have co-operated with the writer are too numerous to mention individually; to all of them he is very deeply indebted. Mr. P. C. Benedict of Newmont Mining Corporation has devoted considerable time to suggestions concerning the westernmost mines; Mr. H. F. Morrow of MacLeod-Cockshutt has similarly helped with those of the eastern part. Mr. H. L. Banting collected several suites of specimens when the writer was forced to leave the field early. Dr. M. H. Haycock of the Mines Branch, Ottawa, and Professor J. Ellis Thomson of the University of Toronto kindly loaned numerous polished sections. Professor E. L. Bruce of Queen's University freely loaned copies of the two theses written by students at that University. Finally, to Professor E. S. Bastin of the University of Chicago, the writer owes most sincere thanks for his suggestions and timely encouragement throughout the progress of this research.

McMaster University,
Hamilton, Ontario,
November 17, 1942.

[33] Moore, E. S.: Genetic relations of gold deposits and igneous rocks in the Canadian Shield. Econ. Geol., 35: 134, 1940.

DISCUSSION AND COMMUNICATIONS

POST-MINE LEACHING OF GALENA AND MARMATITE AT BROKEN HILL.

Sir: In their description of the post-mine leaching of galena and marmatite at Broken Hill, Messrs. Garretty and Blanchard[1] find themselves unable to account satisfactorily for the fact that the more usual order of solubility of these two minerals is here reversed, and that the galena is leached more rapidly than the marmatite. An explanation of this somewhat unusual phenomenon is perhaps provided by the recent work of Garrels.[2]

Garrels showed that the presence of Cl′ ions in Pb–Zn solutions, in concentrations in excess of 0.1 N, rendered the zinc less soluble than the lead. It seems possible that Cl′ ions may be present in the underground waters of the North Broken Hill mine in sufficient concentration to cause such reversal in the relative solubility of the lead and zinc sulphides.

Thus the analysis of "water believed to be free from contamination by mine drainage" given by Messrs. Garretty and Blanchard (p. 386 of their paper) is as follows:

Total solids in solution—	878 grains per gallon
Pb	nil grains per gallon
Zn	28 grains per gallon
Mn	20.6 grains per gallon
Fe	nil grains per gallon
Cl	164 grains per gallon
F	nil grains per gallon
SO_3	400 grains per gallon
CO_2	nil grains per gallon
pH value 6.4	

[1] Garretty, M. D., and Blanchard, Roland: Post-mine leaching of galena and marmatite at Broken Hill. Econ. Geol. xxxvii: 365, 1942.

[2] Garrels, R. M.: The Mississippi Valley type lead-zinc deposits and the problem of mineral zoning. Econ. Geol. xxxvi: 729, 1941.

164 grains of Cl′ per gallon is equivalent to 2.3394 grains of Cl′ per liter, which is equivalent to 0.066 N.

This concentration is approaching a value sufficient to cause a reversal of the relative solubility of zinc and lead salts; and it seems probable that there will be parts of the orebody where locally the Cl′ concentration will greatly exceed this figure. At such points the lead salts would be more soluble than the zinc salts, so that the galena would be leached more rapidly than the marmatite. With the dilution of such Cl′-rich waters with water containing less Cl′, the Cl′ concentration would fall below 0.1 N, and the lead would be reprecipitated, while the zinc would stay in solution, as for example, in the water analysis quoted.

The other point on which the authors speculate is the reason why the Northern Orebody in the mine has undergone greater leaching than the Southern Orebody. Since, however, the Northern Orebody actually overlies the Southern Orebody in any given vertical section, the ground waters must be drained from the Northern Orebody before the Southern Orebody. It seems possible that the greater post-mine leaching of the upper orebody is largely due to the fact that surface waters, in general, reach it first, before they are (*a*) saturated with dissolved minerals, and (*b*) neutralized by the carbonate gangue of the upper or northern orebody.

F. L. Stillwell,
A. B. Edwards.

Melbourne, Australia,
January, 1943.

REVIEWS*

Geology of the Appalachian Valley in Virginia. By CHARLES BUTTS. Part I—Geologic Text and Illustrations. Pp. 568; Pls. 63; Figs. 10. Part II—Fossil Plates and Explanations, Pls. 72. Virginia Geol. Surv., Bull. 52, Charlottesville. Part I, 1940; Part II, 1941. Price, Pts. I and II, $1.50; Pt. I not sold separately; Pt. II, fifty cents.

This excellent work, although based on ten field seasons of study in Virginia, is in a larger sense the result of almost a lifetime of field research by the author in the Appalachian Valley from New York state to Alabama. Many of the conclusions and interpretations of geologic problems in Virginia have been attained as much from knowledge gained elsewhere in the Valley as in Virginia, and the author's wide acquaintance with other portions of the Appalachian Province has made possible the solution of many problems of stratigraphy and correlation which hardly could have been solved from studies in Virginia alone. The special method of work consisted of making numerous traverses across the Valley throughout its length of 400 miles in Virginia; along these traverses many sections were studied in detail and extensive collections of fossils made.

This work is complementary to Virginia Geological Survey Bulletin 42, "Geologic Map of the Appalachian Valley of Virginia with Explanatory Text," published in 1933. The present work has been issued in two parts in order to avoid undue bulkiness and also to make the material of Part II separately available. It is well printed and excellently illustrated throughout with appropriately spaced photographs, maps, and sections.

Part I treats of the geologic relations, topography, drainage, stratigraphy, structure, and geologic history of the Appalachian Valley, or as also known, the Valley and Ridge province of Virginia. The first three of these topics are covered very briefly in the first 21 pages of the text but, although brief, are comprehensive enough to give an adequate background for the other topics. Under "Geologic Structure," pp. 436–468, the author first defines various structural terms and follows this with descriptions of the several faults, anticlines, synclines, and other structural features. The section on "Geologic History," pp. 469–514, summarizes the major events,

* Books noted under *Reviews* and *Books Received* may be ordered through the Economic Geology Bookshop, M. M. Leighton, Urbana, Ill., but orders for official reports and single copies of Journals should be sent directly to their publishers.

both physical and biological, in the geologic past of the area from the beginning of the Paleozoic era through the Pleistocene.

The major portion of Part I, pp. 22–435, deals with the Paleozoic stratigraphy. Each formation is discussed under a uniform set of headings: name, limits, character, distribution, thickness, and fossils and correlation. Although some workers in this region have advocated simplification of nomenclature by using the same name for a stratigraphic unit wherever it can be demonstrated to be the same, Dr. Butts has included all the valid names for each stratigraphic unit so that no confusion need arise. In so doing he has discussed equivalent units together as (1) Hampton-Harpers shale, (2) Lowville-Moccasin limestone, (3) Glen Dean limestone-Bluefield shale-Cove Creek limestone. The treatment of each formational unit is as complete as is consistent with a work of this magnitude. Many detailed sections, complete fossil lists, and illustrations of distinctive lithologic features are given in addition to the text discussions.

For most portions of the geologic column where there are differences of opinion as to the proper classification, Dr. Butts has given both sides of the question consideration and some of the assignments made in this work are not the ones which he personally would prefer, but they have been so made in order to harmonize with the policy of the Virginia Geological Survey, the U. S. Geological Survey, or the correlation subcommittees of the National Research Council, Division of Geology and Geography. Some of the more significant portions of the geologic column which have received such classification treatment are: (1) the section below the Erwin quartzite-Antietam sandstone, considered pre-Cambrian by some; (2) the Richmond group; and (3) the Keyser limestone. One exception to such unbiased treatment may be noted (p. 379). Dr. Butts in referring to the Mississippian in southern Illinois and western Kentucky still includes all of the Ohara limestone in the Ste. Genevieve formation despite the fact that most geologists working with these rocks believe that the "Ohara" is a composite unit, the upper portion of which is the same as the Renault formation of the Lower Chester of western Illinois, with only the lower portion (Levias limestone) a part of the Ste. Genevieve, as shown by A. H. Sutton and J. M. Weller.

Part II is composed of 72 plates of Paleozoic fossils comprising 1,979 figures, most of which are from original photographs by Charles E. Resser of the U. S. National Museum, 187 pages of text explaining the plates, and 11 pages of index. The figures illustrate 604 named and 116 unnamed species. Of the 604 named forms, 51 are only compared with described species and 15 others show affinities with definitely determined forms. One genus, 17 species, and two varieties are described as new. The description of each new form is given in the explanation of the plate

on which it is illustrated. Descriptions are very brief and are largely concerned with emphasizing the features which distinguish each new form from its nearest allies.

Dr. Butts is to be congratulated for the valuable contribution which he has made to our knowledge of the Paleozoic stratigraphy and paleontology of the Appalachian Valley in Virginia. The Virginia Geological Survey is likewise to be commended for making available this summation of the geologic investigations of the author over such a large area during such a length of time. It is a work which no student of Appalachian geology can afford to be without and one which should prove to be of inestimable value to all students of Paleozoic paleontology.

A. H. SUTTON

ALUMINUM ORE CO.,
ROSICLARE, ILL.

America At War. Edit. by SAMUEL VAN VALKENBURG. Pp. xiv + 296; Figs. 54. Prentice-Hall, Inc., New York. 1942. Price, $2.50.

In "America At War, A Geographical Analysis," one of the Prentice-Hall Geography Series, six geographers in search of a better world have set out to prove Spykman's statement that "geography is the most fundamental factor in the foreign policy of states because it is the most important." To do this they have not considered "place geography" but the importance of position, climate, land relief (particularly coastal), natural resources, population with its training and capacities, food supplies and potentials, distribution of mineral resources in the earth and sources of non-metallic raw materials. The claim that geographers long ago learned that isolation for any nation is impossible and that as students of world problems they know that some plan must be worked out for cooperation among the peoples inhabiting the earth permits inclusion of a final chapter on America and Peace. This all results in an interesting and stimulating book.

Ellsworth Huntington, considering the Quality of the People, remarks that if vigor alone were the determining factor, the white population of the United States would be more than a match for England, Germany and the Netherlands, and the high industrial productivity per worker points to a similar conclusion. His rather unique measurement of quality of the people leaves no doubt that the capacity of American people is great and his study provides statistical support that without the greatest natural resources in the world the quality of the people alone would enable us to defend ourselves, but in proportion to our opportunities we have by no means reached the final goal.

Wallace Atwood on Our Land and its Coastline stresses that self-appointed war strategists on coastal defense often overlook the fact that the total length of coastline of the United States and Alaska is one and one-half times the distance around the world at the equator. He reminds us that the great interior plains, bordered both east and west by formidable mountain barriers, is the most remarkable food-producing area of the world.

Samuel Van Valkenburg on Terrain and War Strategy makes some interesting topographic comparisons of ancient and modern battlefields, showing that modern military technique has changed the protective value of natural barriers. The most interesting of these he calls Thermopylæ 480 B.C. and 1941 A.D.

Van Valkenburg also considers the Climatic Factor in timing campaigns, taking advantage of bad weather conditions as well as good.

W. E. Ekblaw in Foods for Defense, summarizing food requirements, procurement, and producing sections, concludes that "the country as a whole is abundantly supplied with food to yield adequacy, variety, quality, and balance of diet for the strength and health necessary to sustain morale, maintain a high standard of productive efficiency and win the war, but there are regions of local insufficiency of food which might become critically vulnerable for defense should our transport system prove inadequate."

In Industrial Capacity and Supplies of Raw Materials, Clarence F. Jones, taking account of all raw materials, manufacturing capacity and man power, proves that the United Nations, not including the resources of the Philippines, the Netherlands East Indies, Malaya, lower Burma and eastern China, are still in a far better situation to equip for and wage a long war than are the Axis Powers. And, because of our extraordinarily favorable position, "whether we like it or not the burden of the conflict rests heavily on the shoulders of Uncle Sam."

Earl B. Shaw takes up United States Atlantic and Pacific Defense. He devotes considerable attention to the recently acquired Atlantic bases and to Hawaii and Alaska and re-deplores that Guam, Wake and the Philippines were not strongly fortified long ago.

Van Valkenburg on America and Peace modestly says that "planning of a postwar world is above all a geographical problem." After sketching an Axis-dominated world, he suggests four principles for post-war world reconstruction, elaborating the recently publicized eight large economic blocs.

E. M. W.

Handbook for Prospectors and Operators of Small Mines, 4th Edit. By M. W. VON BERNEWITZ, Rev. by H. C. CHELLSON. Pp. 547; Figs. 161. McGraw-Hill Book Co., New York, 1943. Price, $4.00.

In this volume H. C. Chellson, Editor of *Mining Congress Journal,* has edited the material prepared by the late M. W. von Bernewitz for the 4th edition of his popular handbook. In Part I the author has included details of a practical nature for the prospector living in the field, and has expanded (to a full chapter) information pertaining to mining law. Part II contains chapters on mineralogy, elementary geology, and the basic principles of ore occurrence and observation as well as data to aid in sampling, assaying and making field tests of a deposit. Separate chapters are devoted to developing and equipping a prospect and markets and prices. Two thorough chapters on metallic minerals and nonmetallic minerals make up Part III. In Parts IV and V Chellson has brought up to date and discussed ore dressing, equipment and metal prices and ore marketing. A 40-page glossary of geologic and mining terms closes the text. "All this material is designed to aid the prospector and small mine operator in his war effort, as well as post war mining." Important for more than its timeliness, this book should continue as an invaluable "partner" for those for whom it was intended.

R. E. D.

Dolomites and Limestones of Western Ohio. By WILBER STOUT. Pp. xiv + 468; Geol. map. Ohio. Geol. Surv., 4th Ser., Bull. 42, Columbus, 1941.

The State Geologist of Ohio here presents a comprehensive and complete account of the dolomites and limestones of western Ohio. A consideration of the origin of the rocks and the physiographic and structural conditions maintaining is followed by a list and description of each formation. This classification is based on the rock systems present in the area and covers geologic time from pre-Cambrian through Devonian. Individual deposits are discussed according to counties and each of the numerous analyses of samples are intended as a "type" analysis for a district. Chapter IV covers the utilization of the dolomites and limestones of the region and is concluded with a directory of operators in western Ohio including approximate locations of the quarries, the formations worked and chief materials produced. Quarrying methods, manufacturing processes, and marketing conditions are not discussed.

R. E. D.

BOOKS RECEIVED.

RALPH E. DIGMAN.

U. S. Geol. Surv., Washington, 1942.

BULLETINS.

926–C. Occurrences of Molybdenum Minerals in Alaska. PHILIP S. SMITH. Pp. 48; Pl. 1. Price, 15 cents.

928–A. Stratigraphy, Structure, and Mineralization in the Beaver-Tarryall Area, Park County, Colo. Q. D. SINGEWALD. Pp. 43; Figs. 2; Pls. 5. Price, 15 cents.

929. Geology and Ore Deposits of the Chichagof Mining District, Alaska. J. C. REED AND R. R. COATS. Pp. 147; Figs. 24; Pls. 33. Price, $3.35.

930–A & B. Spirit Leveling in Illinois, 1896–1941. Pt. 1, Southern Illinois, Pt. 2, West-Central Illinois. Pp. 918; Figs. 115; Pls. 10. Price, 65 cents (part 1) and 60 cents (part 2).

931–H. Tin and Tungsten Deposits at Silver Hill, Spokane County, Washington. LINCOLN R. PAGE. Pp. 24; Figs. 4; Pls. 5. Price, 30 cents.

931–K. The Wild Horse Quicksilver District, Lander County, Nevada. C. H. DANE AND C. P. ROSS. Pp. 19; Figs. 2; Pls. 3. Price, 25 cents.

931–R. Manganese Resources of the Olympic Peninsula, Washington. CHARLES F. PARK. Pp. 22; Figs. 9; Pls. 7. Price, 35 cents.

931–S. Manganese Deposits in the Paymaster Mining District, Imperial County, California. J. B. HADLEY. Pp. 25; Figs. 5; Pls. 3. Price, 30 cents.

932–D. Geophysical Abstracts 107. October–December, 1941. W. AYVAZOGLOU (Complied). Pp. 44. Price, 10 cents.

935–A. Chrome Resources of Cuba. T. P. THAYER. Pp. 72; Figs. 6; Pls. 20. Price, $1.00.

935–B. Manganese Deposits of Cuba. CHARLES F. PARK, JR. Pp. 22; Figs. 3; Pls. 4. Price, 10 cents.

936–A. Muscovite in the Spruce Pine District, North Carolina. T. L. KESLER AND J. C. OLSON. Pp. 36; Fig. 1; Pl. 1. Price, 35 cents.

936–B. Tungsten Deposits of the Nightingale District, Pershing County, Nevada. WARD C. SMITH AND PHILIP W. GUILD. Pp. 18; Fig. 1; Pls. 4. Price, 40 cents.

936–C. Topaz Deposits near the Brewer Mine, Chesterfield County, South Carolina. CARL FRIES, JR. Pp. 17; Fig. 1; Pls. 4. Price, 30 cents.

936–D. Chromite and Quicksilver Deposits of the Del Puerto Area, Stanislaus County, Calif. H. E. HAWKES, JR., AND OTHERS. Pp. 31; Figs. 10; Pls. 2. Price, 30 cents.

936–E. Manganese Deposits of Cedar Creek Valley, Frederick and Shenandoah Counties, Virginia. W. H. MONROE. Pp. 28; Pls. 4. Price, 35 cents.

936–F. Quicksilver Deposits of the Parkfield District, Calif. E. H. BAILEY. Pp. 25; Fig. 1; Pls. 4. Price, 35 cents.

936–G. Chromite Deposits of Red Bluff Bay and Vicinity, Baranof Island, Alaska. P. W. GUILD AND J. R. BALSLEY, JR. Pp. 14; Figs. 2; Pls. 2. Price, 20 cents.

936–H. Quicksilver Deposits Near the Little Missouri River, Pike County, Arkansas. DAVID GALLAGHER. Pp. 29; Figs. 5; Pls. 13. Price, 55 cents.

936–I. Nickel-Copper Deposits on the West Coast of Chichagof Island, Alaska. W. T. PECORA. Pp. 20; Figs. 5; Pls. 2. Price, 20 cents.

936–K. Tin Deposits of Irish Creek, Virginia. A. H. KASCHMANN AND OTHERS. Pp. 25; Figs. 2; Pls. 2. Price, 10 cents.

936–M. Nickel-Copper Deposit at Snipe Bay, Baranof Island, Alaska. J. C. REED AND G. O. GATES. Pp. 10; Figs. 2; Pl. 1. Price, 10 cents.

936–O. Nickel-Copper Deposit at Funter Bay, Admiralty Island, Alaska. JOHN C. REED. Pp. 11; Figs. 2; Pls. 2. Price, 15 cents.

939–A & B. Geophysical Abstracts 108. January–March and April–June 1942. W. AYVAZOGLOU (Compiled). Pp. 65. Price, 10 cents each.

WATER SUPPLY PAPERS.

889–A. Water Supply of the Dakota Sandstone in the Ellendale-Jamestown Area, North Dakota. L. K. WENZEL AND H. H. SAND. Pp. 81; Figs. 3; Pls. 3. Price, 50 cents.

890. Ground-Water Resources of the Williamette Valley, Oregon. A. M. PIPER. Pp. 194; Figs. 3; Pls. 10. Price, 45 cents.

891. Surface Water Supply of the United States, 1940. Pt. 1, North Atlantic Stope Basins. G. L. PARKER AND OTHERS. Pp. ix + 567; Pl. 1. Price, 70 cents.

892. Surface Water Supply of the United States, 1940. Pt. 2, South Atlantic Slope and Eastern Gulf of Mexico Basins. G. L. PARKER AND OTHERS. Pp. viii + 441; Pl. 1. Price, 50 cents.

893. Surface Water Supply of the United States, 1940. Pt. 3, Ohio River Basin. G. L. PARKER AND OTHERS. Pp. ix + 662; Pl. 1. Price, $1.00.

894. Surface Water Supply of the United States, 1940. Pt. 4, St. Lawrence River Basin. G. L. PARKER AND OTHERS. Pp. v + 213 Price, 25 cents.

895. Surface Water Supply of the United States, 1940. Pt. 5, Hudson Bay and Upper Mississippi River Basins. G. L. PARKER AND OTHERS. Pp. vii + 340; Pl. 1. Price, 40 cents.

896. Surface Water Supply of the United States, 1940. Pt. 6, Missouri River Basin. G. L. PARKER AND OTHERS. Pp. viii +457. Pl. 1. Price, 50 cents.

898. Surface Water Supply of the United States, 1940. Pt. 8, Western Gulf of Mexico Basins. G. L. PARKER AND OTHERS. Pp. viii + 426;Pl. 1. Price, 65 cents.

905. Surface Water Supply of Hawaii, July 1, 1939 to June 30, 1940. G. L. PARKER AND M. H. CARSON. Pp. iv + 136. Price, 20 cents.

908. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1940. Pt. 3, North-Central States. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 288; Figs. 7. Price, 30 cents.

911. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1940. Pt. 6, Southwestern States and Territory of Hawaii. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 240; Figs. 15. Price, 30 cents.

927. Surface Water Supply of the United States, 1941. Pt. 7, Lower Mississippi River Basin. G. L. PARKER AND OTHERS. Pp. vi + 355; Pl. 1. Price, 40 cents.

929. Surface Water Supply of the United States, 1941. Pt. 9, Colorado River Basin. G. L. PARKER AND OTHERS. Pp. vi + 311; Pl. 1. Price, 35 cents.

930. Surface Water Supply of the United States, 1941 Pt. 10, The Great Basin. G. L. PARKER AND OTHERS. Pp. iv + 123; Pl. 1. Price, 25 cents.

931. Surface Water Supply of the United States, 1941. Pt. 11, Pacific Slope Basins in California. G. L. PARKER AND OTHERS. Pp. viii + 417; Pl. 1. Price, 55 cents.

932. Surface Water Supply of the United States, 1941. Pt. 12, Pacific Slope Basins in Washington and Upper Columbia River Basin. G. L. PARKER AND OTHERS. Pp. v + 214; Pl. 1. Price, 25 cents.

933. Surface Water Supply of the United States, 1941. Pt. 13, Snake River Basin. G. L. PARKER AND OTHERS. Pp. vi + 246; Pl. 1. Price, 30 cents.

934. Surface Water Supply of the United States, 1941. Pt. 14, Pacific Slope Basins in Oregon and Lower Columbia River Basin. G. L. PARKER AND OTHERS. Pp. vi + 229; Pl. 1. Price, 35 cents.

940. Water Levels and Artesian Pressure in Observation Wells in the U. S. in 1941. Pt. 5, Northwestern States. O. E. MEINZER, L. K. WENZEL AND OTHERS. Pp. 172; Figs. 6. Price, 25 cents.

U. S. Bureau of Mines, Washington, 1942.

Bull. 450. Metal- and Nonmetal-mine Accidents in the U. S., 1940, (Excluding Coal Mines). W. W. ADAMS AND M. E. KOLHOS. Pp. 51. Price, 10 cents.

Tech. Pap. 641. Analysis of Illinois Coals. Pp. 245; Figs. 11. Price, 30 cents.

Tech. Pap. 642. Hydrogenation and Liquefaction of Coal. C. H. FISHER AND OTHERS. Pp. 162; Figs. 52. Price, 25 cents.

Tech. Pap. 644. Carbonizing Properties and Petrographic Composition of Bakerstown-Bed Coal. J. D. DAVIS AND OTHERS. Pp. 45; Figs. 24. Price, 15 cents.

Tech. Pap. 645 (Supplement of 590). Analyses of Pennsylvanian Bituminous Coals. N. H. SNYDER AND R. J. SWINGLE. Pp. 19. Price, 10 cents.

Tech. Pap. 646. Hydrogenation and Liquefaction of Coal. L. L. HIRST AND OTHERS. Pp. 27; Figs. 19. Price, 10 cents.

SOCIETY OF ECONOMIC GEOLOGISTS

WILLIAM SHIRLEY BAYLEY.

1861–1943.

William Shirley Bayley, geologist, petrologist, mineralogist, and inspiring teacher, died on February 13, 1943, in Glen Rock, New Jersey, at the home of his daughter, Elizabeth Gillen. He continued his work at the University of Illinois as business editor of ECONOMIC GEOLOGY until November, 1942, when failing strength led him to join his daughter where he spent his last months happily enjoying the company of her family. He was buried in Urbana, Illinois, where he had made his home for 35 years.

Dr. Bayley was born November 10, 1861, in Baltimore, Maryland. He entered Johns Hopkins University at a time when he had the exceptional privilege of studying under two of America's most inspiring teachers, Ira Remsen in chemistry, and George H. Williams, who introduced petrography into American geology. Thus was laid the basis for his keen appreciation of the value of chemistry, petrology, and mineralogy in the solution of problems in geology. He received his A.B. degree in 1883, and the Ph.D. degree also from Johns Hopkins University in 1886.

The interest in petrologic problems, through his close association with Williams, led Dr. Bayley to commence a study of the rocks of Pigeon Point, Minnesota, in the summer of 1885. These studies led to the publication of U. S. Geological Survey Bulletin 109, a pioneer study of the origin of an igneous rock. This initiated his work in the Lake Superior region which was destined to be his major geologic interest for many years. In 1886 he joined a field party of the U. S. Geological Survey, first as a volunteer assistant. The following year he began his work on the iron-bearing districts of the region and his associations with R. D. Irving, Van Hise, Smyth, Clements, and Leith. He had a part in the U. S. Geological Survey work in all the iron-bearing districts of the region, was author of the Monograph on the Menomonie district, and joint author with Van Hise and Smyth on those on the Marquette and Crystal Falls districts; he also did much of the field work on the Vermilion district. In addition, many scientific papers on geology and petrography resulted from his studies in the Lake Superior region.

Later, he turned his attention to the crystalline rocks of the Highlands of New Jersey, and his previous work with iron formations led to a de-